United States
Department of
Agriculture

Agricultural
Research
Service

Agriculture
Handbook
Number 66

revised
1986

The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks

Hardenburg, Robert E., Alley E. Watada, and Chien Yi Wang. 1986. The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks. U.S. Department of Agriculture, Agriculture Handbook No. 66 (revised), 136 p.

This handbook discusses factors that can significantly affect the maintenance of quality in fresh fruits, vegetables, and florist and nursery stocks during cold storage. Factors discussed include precooling, heat production by commodity, storage environment, air movement, sanitation, supplements to refrigeration, and various types of injuries that can occur during storage. For each commodity the recommended storage conditions and potential storage life are discussed.

Keywords: air circulation, ammonia injury, chilling injury, commodity storage, controlled atmosphere, freezing injury, fumigation, heat evolution, irradiation, precooling, quality, refrigeration, relative humidity, respiration rates, sanitation, storage, temperature, waxing, weight loss.

Copies of this publication can be purchased from the Superintendent of Documents, Government Printing Office, Washington, DC 20402.

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United States Department of Agriculture

Agricultural Research Service

Agriculture Handbook Number 66

The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks

By

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Chien Yi Wang

Preface

Agriculture Handbook No. 66 is an extensive revision of the 1968 edition written by the late J.M. Lutz and R.E. Hardenburg. An earlier edition (1954) of this handbook was written by R.C. Wright, D.H. Rose, and T.M. Whiteman, all from U.S. Department of Agriculture, Beltsville, MD. Since the 1968 edition, much new research data concerning temperature and humidity requirements and on supplements to refrigeration have been published. This handbook attempts to summarize current storage recommendations for horticultural crops. An extensive, though far from complete, list of references is included for readers desiring further information. The handbook is intended especially for use by persons involved in marketing (storage operators, warehouse personnel, shippers, carriers, wholesalers, inspectors), by research workers, and others concerned with maintaining the quality of fresh fruits, vegetables, flowers, and nursery stocks.

Other related publications of the Department are Agriculture Handbooks

- 105 Protecting Perishable Foods During Transport by Motortruck (Revised Nov. 1970)
- 159 The Cold Storage of Vinifera Table Grapes (1959)
- 195 Protection of Rail Shipments of Fruits and Vegetables (1969)
- 593 Export Handbook for U.S. Agricultural Products (Revised 1985)

(Handbooks 159 and 195 are out of print but are available at State agricultural libraries and the National Agricultural Library in Beltsville, MD.)

Acknowledgments

The writers have drawn freely on published and unpublished findings and the experience of staff members and others whose assistance and cooperation have done much to make this publication possible. Especial acknowledgment for reviewing certain sections and for information on indicated subjects is due the following researchers: Vegetables, W.J. Lipton (USDA), Fresno, CA, J.R. Hicks and Pamela Ludford, Cornell University; fruits, R.E. McDonald and T.T. Hatton, Jr. (USDA), Orlando, FL, K.L. Olsen (USDA), Wenatchee, WA, and G.D. Blanpied, Cornell University; flowers, F.J. Marousky (USDA), Gainesville, FL, and A.M. Kofranek, University of California (Davis).

Acknowledgment is also due to the following for information on indicated subjects: Citrus, W.F. Wardowski, University of Florida (Lake Alfred), and L.C. Houck (USDA), Fresno, CA; potatoes, W.C. Sparks, University of Idaho, and S.S. Leach (USDA), Orono, ME; apples, E.M. Kupferman, Washington State University, G.D. Blanpied, Cornell University, and K.L. Olsen (USDA), Wenatchee, WA; cranberries, M.E. Patterson, Washington State University; grapes, K.E. Nelson, University of California (Davis); pomegranates, F.G. Mitchell, University of California (Davis); citrus juices, R.E. Berry (USDA), Winter Haven, FL; cantaloups, W.J. Lipton (USDA), Fresno, CA, and R.F. Kasmire, University of California (Davis); southern peas, D.A. Smittle, University of Georgia (Tifton); ornamentals, J.R. Havis, University of Massachusetts, and F.R. Gouin, University of Maryland; bedding plants, A.M. Armitage, University of Georgia (Athens), and Louella J. Nelson, Michigan State University; foliage plants, C.A. Conover, University of Florida (Apopka); rose bushes, H.B. Pemberton, Texas A&M University (Overton); cut flowers, A.M. Kofranek, University of California (Davis), and G.L. Staby, Perishables Research Organization, Novato, CA.

Help in obtaining illustrations by the following is appreciated: J.B. Fountain (USDA), Wenatchee; J.M. Harvey (USDA), Fresno; and J.R. Havis, University of Massachusetts.

Contents

Introduction 1
Factors Involved in Cold Storage 1
- Product Quality 1
- Temperature 2
- Precooling 3
- Relative Humidity 6
- Air Circulation and Package Spacing 7
- Respiration Rates, Heat Evolution, and Refrigeration 9
- Weight Loss in Storage 19
- Sanitation and Air Purification 21
- Supplements to Refrigeration 22
- Chilling Injury 25
- Freezing Injury 25
- Ammonia Injury 27
- Effect of Cold Storage on Subsequent Behavior of Fruits and Vegetables 27

Mixed Commodities 28
Fresh Fruits 29
- Apples 29
- Apricots 35
- Avocados 35
- Bananas 36
- Berries 37
- Cherries 39
- Coconuts 39
- Dates 39
- Figs, Fresh 40
- Grapefruit 40
- Grapes 41
- Guavas 42
- Kiwifruit 42
- Lemons 42
- Limes 43
- Loquats 43
- Lychees 44
- Mangos 44
- Olives, Fresh 44
- Oranges 44
- Papayas 45
- Peaches and Nectarines 46
- Pears 47
- Persimmons, Japanese 48
- Pineapples 48
- Plums, Including Prunes 49
- Pomegranates 49
- Quinces 49
- Tangerines, Mandarins and Related Specialty Citrus Fruits 49

Fresh Vegetables 50
- Artichokes 50
- Asparagus 52
- Beans 52
- Bean Sprouts 53
- Beets 54
- Broccoli (Italian, or Sprouting) 54
- Brussels Sprouts 54
- Cabbages 55
- Carrots 55
- Cassava 56
- Cauliflower 56
- Celeriac 57
- Celery 57
- Chicory (Witloof or Belgian Endive) 57
- Corn, Sweet 58
- Cucumbers 58
- Eggplants 59
- Endive and Escarole 59
- Garlic, Dry 59
- Ginger 59
- Greens, Leafy (Collards, Kale, Rape, Swiss Chard, and Beet Greens) 59
- Horseradish 60
- Jicama 60
- Kohlrabi 60
- Leeks 60
- Lettuce 60
- Melons 61
- Mushrooms, Cultivated 62
- Okra 62
- Onions 63
- Onion Sets 64
- Parsley 64
- Parsnips 64
- Peas 64
- Peppers 65
- Potatoes 66
- Pumpkins and Squashes 68
- Radishes 69
- Rhubarb 69
- Rutabagas 69
- Salsify 69
- Spinach 69
- Squashes 70
- Sweetpotatoes 70
- Tamarillos 71
- Taro (Dasheens) 71
- Tomatoes 71
- Turnips and Turnip Greens 72
- Waterchestnuts 72
- Watercress 72
- Yams 72

Dried Fruits and Vegetables 73
Frozen Fruits, Vegetables, and Fruit Juice Concentrates 73
Chilled Citrus Juices and Citrus Fruit Salads 74
Nuts (Including Peanuts) 74
Cut Flowers and Florist Greens 75
- Marketing Cut Flowers 75
- Causes of Deterioration of Cut Flowers 81
- Factors Affecting Cut Flower Longevity 81
- Storage and Handling Details for Certain Flowers 88
- Florist Greens (Decorative Foliage) 91

Nursery Stock and Related Materials 92
- Bulbs, Corms, Rhizomes, Roots, and Tubers 92
- Flowering Potted Plants 94
- Foliage Plants 95
- Cuttings and Scions 96
- Bedding Plants and Seedlings 96
- Seeds and Pollen 97
- Herbaceous Perennials 98
- Woody Ornamentals 99
- Miscellaneous Plants and Christmas Trees 101

Literature Cited 102

The Commercial Storage of Fruits, Vegetables, and Florist and Nursery Stocks

Robert E. Hardenburg, Alley E. Watada, and Chien Yi Wang[1]

Introduction

This handbook presents brief summaries of the storage requirements of fresh fruits, vegetables, cut flowers, and certain other horticultural crops. The function of fruit or vegetable storage is to provide an environment that minimizes deterioration until the final steps in marketing. Often the purpose of storage is to allow sale at a later date, thus extending the marketing period.

General topics, such as quality, precooling, relative humidity, respiration rates, and supplements to refrigeration, are covered in the preliminary section. Many details are necessarily omitted, as the handbook is intended primarily for general practical reference. The conditions given should not be considered absolute or final but rather as the safe limitations under which the various products can ordinarily be stored.

The temperatures recommended are the optimum for long storage. For short storage, higher temperatures may be satisfactory for some commodities. Conversely, products susceptible to chilling injury can sometimes be held at a temperature lower than indicated for several days without injury. Exceptions include bananas, cucumbers, eggplant, okra, pumpkins and squashes, potatoes for processing, sweetpotatoes, mature-green tomatoes, and orchids. Still other chilling sensitive products are identified in relevant text sections. Recommended temperatures for these products should be strictly adhered to. Susceptibility to chilling is discussed in greater detail under "Chilling Injury" and under the individual commodities.

Detailed information on the handling and storage of many of the commodities discussed is available in textbooks (*789, 790, 891*) and in publications listed under "Literature Cited." Summaries of storage recommendations for some produce are given in the references numbered *33, 276, 337, 428, 712, 727, 768, 942, 954, 1049.* Recommendations for storage of lesser known tropical fruits and vegetables are given in *688, 1004.* Suggestions for home storage of fruits and vegetables are given in *561, 969.* Recommendations for handling frozen foods are summarized in *427.* Excellent information on the magnitude of losses during storage, transportation, and marketing of perishable foods is reported in *1079.*

Decay induced by fungi and bacteria and deterioration due to physiological changes are too broad subjects to be discussed in detail in this publication; they are merely discussed generally in connection with various fruits and vegetables covered. For further information on diseases see references *367, 368, 606, 718, 748, 749, 851, 869, 889.* A brief review of the principal diseases is given in *194. 229, 318.*

[1]Respectively, research horticulturist (retired), research food technologist, and research horticulturist, Horticultural Crops Quality Laboratory, U.S. Department of Agriculture, Agricultural Research Service, Beltsville, MD 20705.

Factors Involved in Cold Storage

Recommendations for the best conditions for storage of fresh fruits, vegetables, and cut flowers may change from time to time as cultivars and handling methods change and as more information is gained on storage requirements of these commodities. The conditions and requirements given are based on the best commercial practices in 1984 and on scientific experimentation. Temperature requirements represent commodity temperatures that should be maintained.

Product Quality

Commodities should be in excellent condition and have excellent quality if maximum storage life is desired. The commodities should be as free as possible from skin breaks, bruises, decay, and other deterioration. Bruises and other mechanical damage not only detract from the appearance of the product but are good avenues of entrance for decay organisms. Decay has been shown to be greater in bruised areas of apples than in unbruised areas (*1072*). Severely bruised prunes developed 25 percent decay, whereas unbruised prunes developed 1.3 percent during storage (*144*). Mechanical damage also allows increased moisture loss. The rate of moisture loss may be increased by as much as 400 percent by a single bad bruise on an apple. Suggestions for minimizing bruising of apples are given in *818.* Skinned potatoes may lose three to four times as much weight as nonskinned ones, (*342*).

Products for storage should be harvested at optimum maturity, because storage life may be reduced if they are immature or overmature. The proper maturity for storing some products is discussed under individual commodity requirements or in publications listed under "Literature Cited."

Fresh produce may have incipient infection, generally not visible, which causes decay and rot during storage. The amount of incipient infection should be determined prior to storage, as described for grapes and apples grown in the West (*363, 716*). Only lots free of infection should be considered for long-term storage.

Most commodities should be precooled, and all should be placed in recommended storage condition immediately after harvest for maximum storage life. Storage life may differ with lots of fruits and vegetables, due to differences in cultivars, climatic and soil conditions, cultural practices, maturity, and handling practices before storage. Appropriate allowances should be made for products grown under unfavorable conditions or transported a long distance.

Temperature

All temperature recommendations in this handbook are given in degrees Celsius. Often the Fahrenheit equivalent also is shown in tables or in the text in parentheses. Some useful conversions for the two scales follow:

°C	°F	°C	°F
−1	30.2	13	55.4
0	32.0	15	59.0
1	33.8	20	68.0
2	35.6	25	77.0
5	41.0	30	86.0
7	44.6	35	95.0
10	50.0	40	104.0

Temperature conversion:

°C = (°F − 32) × 5/9   1°C = 1.8°F
°F = (°C × 9/5) + 32   1°F = 0.56°C

Refrigerated storage is recommended for many perishable commodities because it retards (1) aging due to ripening, softening, and textural and color changes; (2) undesirable metabolic changes and respiratory heat production; (3) moisture loss and the wilting that results; (4) spoilage due to invasion by bacteria, fungi, and yeasts; and (5) undesirable growth, such as sprouting of potatoes.

If the best results are to be obtained in the cold storage of the products discussed herein, it is highly important that the temperature in storage rooms be held fairly constant. Variations of 1° or 2°C above or below the desired temperature are too large in most cases for prolonged storage. For example, most cultivars of apples keep best if held constantly at −1° to 0°; the best temperature for pears is between −1.5° and −0.5°. If the storage temperature for either of these fruits rises 1° or 2° above the upper limit mentioned or if the commodity is not cooled promptly to these temperatures, there is danger of increased decay and undue ripening. The danger is greater the longer the period during which the temperature is above the optimum. For example, 3 or 4 days at 1.5° usually would have little or no effect, partly because the temperature of the fruit will not rise as quickly as that of the air; but 10 days at this temperature would probably shorten the life of the fruit by about a week and possibly result in more decay. On the other hand, if the temperature falls 1° or 2° below −1.5° for pears, there is a good chance that they will freeze. It is important that the temperature of the commodity be kept within the recommended range. Celery and cabbage allowed to remain too warm in storage will yellow and decay; potatoes are likely to begin sprouting if the temperature is too high and may become undesirably sweet if it is too low. Other commodities undergo these or other kinds of deterioration if the temperature variations throughout long storage periods exceed the limits given for them in this handbook. In addition, fluctuations in temperature often cause condensation of moisture on stored products, which is undesirable because it may favor the growth of surface mold and the development of decay.

Maintaining uniform temperatures in all parts of a storage room is more important than avoiding small fluctuations at a given point. Fruit stored in a part of the room where temperature is continuously higher than in another part ripens faster than that stored in the cooler part. This situation frequently results in mixing of overripe and prime fruit on removal, or it may result in undetected deterioration and decay in inaccessible locations (*422*).

Temperature variations can usually be prevented if the storage rooms are well insulated throughout and have adequate refrigeration and if the spread between the temperature of the refrigerant and that of the rooms is kept small. Proper stacking and adequate air circulation also help to minimize temperature variation. Storage rooms should be equipped either with reliable, accurate thermostats or with manual controls that are given frequent personal attention by someone charged with that duty. Even when reliable automatic controls are used, they should be checked periodically.

In commercial cold-storage rooms, thermometers are usually placed about 1.5 m from the floor for convenience in reading. It is important, however, to take temperatures frequently at the floor and the ceiling levels and at any other places that might be expected to be undesirably warm or cold. It would be shortsighted to rely on just one or two aisle temperatures.

Product temperatures should be taken in packages or within bulk containers at various locations. A thermometer of good quality is essential; a poor one cannot be expected to give accurate readings. Either a glass stem thermometer or a metal dial thermometer is recommended for taking temperatures of fresh produce. The thermometers should be checked frequently to ensure their accuracy. The test can be made by immersing a thermometer

in an ice-and-water bath. Fill a pint-size container with chipped ice and then add water. Stir for 2 minutes, and then immerse the thermometer for 2 minutes in the center of the mixture. Do not permit the thermometer bulb to rest against the side or bottom of the container. The thermometer should read within 0.5°, plus or minus, of 0°C (*305*).

Temperatures in less accessible locations, such as the middle of stacks, can be obtained conveniently with distant-reading thermometer equipment, such as thermocouples or electrical resistance thermometers.

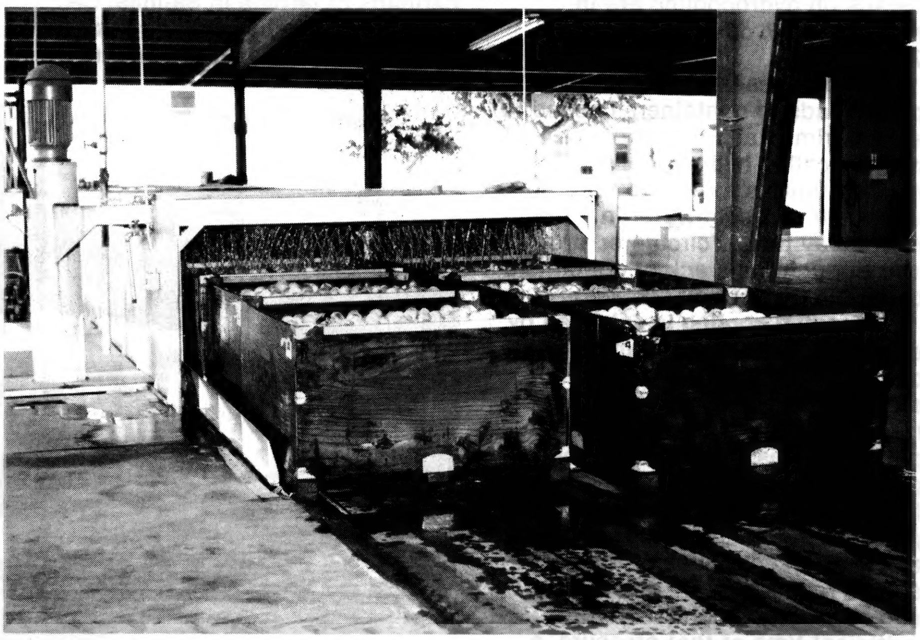
Precooling

Precooling refers to the rapid removal of field heat from freshly harvested commodities before shipment, storage, or processing, and is essential for many perishable horticultural crops. Properly carried out, precooling reduces spoilage and helps retard loss of preharvest freshness and quality. Precooling is the first step in good temperature management. Delays at high temperatures between harvest and the start of precooling are certain to increase deterioration. Prompt cooling to required temperatures inhibits growth of decay-producing microorganisms, restricts enzymatic and respiratory activity, inhibits water loss, and reduces ethylene production by the product.

Most storage rooms designed for holding produce under refrigeration have neither the refrigeration capacity nor the air movement needed for rapid cooling. Thus, precooling is generally a separate operation that requires special equipment and/or rooms. Precooling is accomplished commercially by several methods: hydrocooling, vacuum cooling, air cooling, and contact icing (package icing). There are variations of each, but all involve the rapid transfer of heat from the commodity to a cooling medium, such as water, air, or ice. From 20 minutes or less to 24 hours or more may be required for adequate cooling.

The rate of cooling of any commodity depends primarily upon four factors, although not all are applicable to all cooling methods: (1) the accessibility of the product to the refrigerating medium; (2) the difference in temperature between the product and the refrigerating medium; (3) the velocity of the refrigerating medium; and (4) the kind of cooling medium (*788*). The **half-cooling time** is the time required to reduce the temperature difference (commodity temperature minus the coolant temperature) by one-half. The concept of half-cooling time lends itself to calculations of precooling because, theoretically, the half-cooling time is independent of the initial temperature and remains constant throughout the cooling period. Thus, once the half-cooling time has been determined for a given crop and cooling condition, prediction of cooling accomplished in a certain interval is possible, regardless of the temperature of the product or coolant (*789, 922*). Instructions for using half-cooling times and nomographs to predict final commodity temperature when vegetables are hydrocooled are given in reference *922*.

Hydrocooling is a rapid and effective method of precooling if done properly (fig. 1). Cooling is accomplished by flooding with, spraying with, or immersing in cold water. Enough refrigeration must be supplied to keep the water temperature at about 1°C despite variations in initial product temperature. Two basic systems of hydrocooling are used: a flow-through or conveyor system and a batch system. In a conveyor hydrocooler, the product is either showered with or submerged in cold water as it progresses through the cooler. The product may be in a single layer, multiple layers, in bulk bins, or in packed boxes. Good commercial hydrocoolers provide overhead showering (flooding) at a rate of 400 to 600 L/m^2/minute (10 to 15 gal/ft^2/minute). The batch-type hydrocooler is normally a room in which palletized unit loads of product are stacked one to three pallets high and cooled with cold water sprayed from overhead nozzles. Palletized crates of celery and sweet corn are sometimes hydrocooled in this manner. Hydrocooling is slower for crated products than for loose nonpacked products because the water is shed by the crates and also



PN-7217

Figure 1
Hydrocooling of peaches in pallet bins with cold water (near 0°C) immediately after harvest. (Courtesy of Durand-Wayland, Inc.)

does not readily penetrate to the tightly packed product.

Too often the water in hydrocoolers is not cold enough, its flow rate is inadequate, or produce is not left in the hydrocooler long enough. Peaches 7.6 cm (3 in) in diameter may take 30 minutes to cool from 32°C to 4° in 1.6° (35°F) water, while peaches 5.1 cm (2 in) in diameter can be cooled the same amount in 15 minutes (*80*). Usually the water in hydrocoolers is recirculated repeatedly—a practice that leads to some accumulation of decay-producing micro-organisms and, thus, a sanitation problem. The cooling water should be constantly treated with chemicals such as hypochlorite solutions to minimize the buildup of pathogenic organisms. Hydrocoolers should be drained and cleaned daily.

Commodities often hydrocooled are asparagus, celery, cantaloups, green peas, peaches, radishes, tart cherries, snap beans for processing, and sweet corn. Commodities sometimes hydrocooled include cucumbers, peppers, other melons, and early-crop potatoes. Tart cherries are cooled to about 10°C by holding in cold-water tanks (*709*). Further details on hydrocooling are in references *33, 534, 631, 708, 709, 786, 789, 918*.

Recent research on cooling pallet loads of containers has led to an experimental concept of precooling called **hydraircooling.** The method utilizes a mixture of refrigerated air and cold water in a fine-mist spray that is circulated around and through the stack of containers by forced convection (*78, 388*).

Vacuum cooling is achieved by enclosing vegetables in an air-tight chamber and rapidly pumping out air and water vapor. Water is vaporized in a vacuum chamber under low pressure; thus, cooling is accomplished by evaporation of water from the product surfaces. As the pressure in the chamber is reduced, evaporation continues. If the pressure is reduced to 4.6 mm mercury and evaporation continues for a sufficient time at that pressure, a commodity temperature of 0°C (32°F) will be reached. At ordinary atmospheric pressure (760 mm mercury), water boils at 100° (212°F). However, if the pressure is reduced to 4.6 mm mercury, water boils at 0°. Precooling is accomplished in a vacuum cooler by literally boiling water off the product (*33, 65, 256, 709*). Moisture loss during vacuum cooling of vegetables ranges from 1.5 to 5 percent. Since this moisture loss occurs about equally from all parts of produce being cooled, wilting is not apparent unless water loss exceeds about 5 percent. About 1 percent of the weight is lost for every 5.6°C (10°F) lowering in temperature (*66*).

The vacuum chambers used vary greatly in size. The small, portable units have a capacity of a few pallets, whereas the large, stationary ones each hold up to two carloads. Pairs of the large chambers sometimes operate alternately. Some of the older coolers still use steam jets to achieve the vacuum needed for cooling, but almost all of the newer installations use rotary vacuum pumps for this purpose (*33, 432*).

Vacuum cooling is the standard commercial method of cooling crisphead lettuce (fig. 2). It was used for the first time in 1948 to precool 34 carloads of lettuce in Salinas, CA. The rate of cooling and the final temperature attained by vacuum cooling are affected largely by the ratio of the surface area of the commodity to the mass, the ease with which the product gives up water from its tissues, and the rate at which the vacuum is drawn in the chamber. Thus, fruits and vegetables differ widely in their adaptability to this precooling method (table 1). Lettuce, with its vast leaf area for evaporation, is readily adapted and can be cooled from 21°C to 2° in 25 to 30 minutes in packed cartons. Actually, the time required commercially to cool lettuce to 2° varies from about 15 minutes for fairly firm lettuce to 50 minutes or longer for very dense lettuce weighing 60 lb or more per carton (*432*). Other leafy vegetables, such as spinach, endive, escarole, and parsley are also well adapted to cooling by vacuum. Several other vegetables sometimes are vacuum cooled, especially if prewetted or misted to supply some of the water needed for vacuum cooling and consequently reduce the amount of moisture lost from within tissues (*67*). These include asparagus, artichokes, broccoli, cauliflower, cabbage, celery, brussels sprouts, leeks, mushrooms (not prewetted), and sweet corn. Products with low surface-to-mass ratios, such as tree fruits, most root crops, and

Figure 2 PN-7164

Vacuum cooling of lettuce in fiberboard cartons. Cartons spaced to allow movement of air.

Table 1
Effectiveness of vacuum cooling fruits and vegetables with different surface-area-to-volume (SV) ratios[1]

Surface-to-volume ratio & commodity	Container type	Duration of vacuum (min)	Commodity temperature Initial °C	Initial °F	Final °C	Final °F
Large SV ratio						
Brussels sprouts	Quart cup	20	20	68	3	38
Endive	Crate	20	20	68	2	36
Lettuce, head	Carton	13	22	71	2	36
Spinach	Basket	10	19	67	3	37
Medium SV ratio						
Beans, snap	Hamper	20	27	80	16	60
Cauliflower	Crate	20	24	76	7	44
Celery	Crate	13	21	70	8	47
Sweet corn	Crate	20	28	83	6	43
Small SV ratio						
Carrots, topped	Crate	45	19	66	16	60
Cucumbers	Basket	20	26	78	23	73
Potatoes	None	30	18	65	14	57
Tomatoes	Cello-tray	20	25	77	22	71

[1] Adapted from Friedman and Radspinner (*256*).

tomatoes, are better adapted to other cooling methods. Vacuum cooling is particularly well adapted to certain vegetables packed in fiberboard cartons and in film-wrapped consumer packages if they are adequately ventilated to allow evaporation of moisture. (See *65, 256, 282, 456, 631, 789.*)

Air cooling is accomplished by using either **room cooling** or **forced-air cooling** (pressure cooling) systems. Water loss can be a problem in air cooling but can be almost eliminated by providing highly humid air. Relative humidities of 95 percent or above are now used by many operators.

Room cooling by exposure of produce in containers to cold air in refrigerated spaces is a common cooling method. For such products as apples, citrus, and pears, room cooling may be performed in the same refrigerated space used for temporary or long-term storage. Best results are obtained when there is enough refrigerated air to keep all parts of the room cold and an air velocity of 60 to 120 m/minute is used around and among the containers (*631*). Containers must be properly stacked to permit air flow between them. Separate cooling rooms with powerful fans to provide high air velocity are often used if the cooling in storage rooms is not considered satisfactory. Many plants of this type are used in California for grapes and tree fruits. Shipping containers are handled on pallets. The cooling rooms are emptied and refilled each day or every other day (*33*). Effective cooling may require 18 to 24 hours or even longer.

Forced-air cooling of produce is accomplished by producing a difference in air pressure on opposite faces of stacks of vented containers. This difference forces air through the stacks and carries produce heat away, primarily by flow around the individual products in the containers. Rapid cooling can be accomplished with adequate refrigeration and a large volume of air flow per unit of produce. Forced-air cooling usually takes only one-fourth to one-tenth the time needed for room cooling but still takes at least twice as long as hydrocooling or vacuum cooling. Forced-air cooling offers a practical solution for cooling fresh fruits, vegetables, melons, and cut flowers that cannot be hydrocooled or are not adaptable to vacuum cooling. It is effective for most commodities, but it is especially useful for strawberries, grapes, fruits, melons, and vine-ripe tomatoes, and sometimes useful for cucumbers, peppers, and cauliflower (*33, 456, 631, 709*). Forced-air cooling is the common method of precooling cut flowers packed for shipment (*761*). When strawberry trays are stacked on pallets and placed with a suction duct opposite each tray, they can be cooled from 24°C to 4° in 1 1/4 hours using 0.5° air (*709*). Readers are referred to reference *631* for the design of air cooling facilities.

Package icing is an old method that involves placing finely crushed ice within shipping containers. It can be effective in cooling products that are not harmed by contact with ice. Spinach, collards, kale, broccoli, brussels sprouts, radishes, green onions, carrots, and cantaloups are products commonly marketed with crushed ice in shipping containers. To cool produce from 35°C to 2° requires the melting of ice equal to 38 percent of the product's weight. Additional ice must be melted to remove heat leakage into the packages from outside. **Top icing**, the placing of ice on top of packed containers, is still practiced to further reduce product temperature and provide water to maintain freshness in transit. Top icing is now used primarily as a supplement to one of the principal precooling methods (hydrocooling, vacuum cooling, forced-air cooling) for crated sweet corn, celery, and some other leafy vegetables, and for radishes and carrots prepackaged in film bags.

The choice of a precooling method must be related to availability of facilities, cost, type of container, nearness to market, and produce requirements. Some products, cantaloups for example, may be successfully precooled in several ways but not by vacuum. Iceberg lettuce, on the other hand, can be effectively cooled by only one method—vacuum cooling. Pulp temperatures should be taken before and after precooling to determine the extent of cooling achieved. Regardless of the method of precooling, much of

the benefit will be lost if products are not promptly refrigerated afterwards. (See also *292, 705, 754.*)

Relative Humidity

The humidity of the air in storage rooms directly affects the keeping quality of the products held in them. If it is too low, wilting or shriveling is likely to occur in most fruits, vegetables, cut flowers, and related products. Maintaining humidity high enough in commercial storage is usually a greater problem than the occurrence of too high humidity. High humidity is beneficial for wound healing and periderm formation during curing of certain crops.

All humidity recommendations in this handbook are expressed as relative humidity. Relative humidity is defined as the ratio of the water vapor pressure in the air to the saturation vapor pressure at the same temperature, and is normally expressed as a percent (*260*). The difference in vapor pressure can cause water vapor movement from or to objects in contact with the air. The water-holding capacity of air increases as the temperature rises; hence, air at 90 percent relative humidity at 10°C contains more water by weight than air at 90 percent relative humidity at 0°. Nevertheless, water would be lost from a product at about twice the rate in a room at 10° than at 0° if the relative humidity is 90 percent in both.

High relative humidities, 85 to 100 percent, are recommended for most perishable horticultural products to retard softening and wilting from moisture loss. Exceptions, such as nuts, dates, dried fruits, onions, and bulbs, are discussed under the individual commodity. For most vegetables, the relative humidity should be about 90 to 100 percent. If it is necessary to increase the relative humidity in rooms used for common storage, or air-cooled (nonrefrigerated) storage, water may be sprinkled on the floor occasionally or misters may be installed. The relative humidities recommended are those that will retard moisture loss and that do not favor excessive growth of micro-organisms. Some moisture loss has to be accepted. (See also *26, 33, 245, 259, 567, 568, 715.*) For a more detailed discussion of relative humidity as it relates to weight loss, see p. 19 to 20.

Of major importance in maintaining adequate relative humidity in the storage air is providing good insulation, avoiding air leaks, and providing sufficient cooling surface so that the spread between the temperature of the refrigerating surface (dry coil or wet coil evaporators) and the desired commodity temperature is as small as possible. Therefore, accurate control of refrigerant temperature is essential for maintaining high humidities in a mechanically refrigerated storage. As the difference between the temperature of the refrigerating surface and the temperature of the air in contact with the refrigerating surface increases, the humidity decreases.

The data in table 2 indicate the relative humidity that could be expected with certain air and refrigerating-surface temperatures (assumed to be approximately at the dewpoint). For example, if the air moving over the refrigerating surface is cooled to −1.1°C and the surface temperature is −3.9°, the relative humidity of this air will be about 78 percent, because any water vapor in excess of the amount that can be held at this relative humidity will condense on the coil or spray. However, if air at −1.1°C moves over a refrigerating surface maintained at −2.8°, the relative humidity will be 89 percent; and if, instead, the air moves over a refrigerating surface at −1.7° (a temperature difference of only 0.6°), then a relative humidity of 94 percent could be expected. Actual humidities obtained under these conditions of refrigerating surface and air temperatures will usually be somewhat

Table 2
Relation of dewpoint to air temperature and relative humidity[1]

Dewpoint[2]		Air temperature (dry bulb)		Depression of wet bulb		Relative humidity
°C	°F	°C	°F	°C	°F	(percent)
−2.2	28	−1.7	29	0.28	0.5	94
−3.3	26	−1.7	29	.56	1.0	88
−5.0	23	−1.7	29	1.11	2.0	77
−1.7	29	−1.1	30	.28	.5	94
−2.8	27	−1.1	30	.56	1.0	89
−3.9	25	−1.1	30	1.11	2.0	78
−1.1	30	−.6	31	.28	.5	94
−2.2	28	−.6	31	.56	1.0	89
−3.3	26	−.6	31	1.11	2.0	78
−.6	31	0	32	.28	.5	95
−1.1	30	0	32	.56	1.0	89
−2.8	27	0	32	1.11	2.0	79
−.6	31	.6	33	.56	1.0	90
0	32	1.1	34	.56	1.0	90
.6	33	1.7	35	.56	1.0	91
1.1	34	2.2	36	.56	1.0	91
3.3	38	4.4	40	.56	1.0	92
1.7	35	4.4	40	1.11	2.0	83
8.9	48	10	50	.56	1.0	93
7.8	46	10	50	1.11	2.0	87

1 For further information, see reference *585*.
2 Discussions in the text relating to this table assume that dewpoint and refrigerating-surface temperature are the same.

higher than indicated, because not all the air comes in contact with the refrigerating surface. Thus, air leaving the chamber will be a blend of that which has lost moisture and that which has retained its original moisture content (*788*).

As the difference between refrigerant temperature and air temperature becomes narrower, a greater refrigerating surface is necessary. If air is cooled from 0° to −1.1°C during passage through a dry-coil bunker, considerable more surface will be required to accomplish this temperature reduction when the coil is operated at −1.7° than when it is operated at −3.9°. With an adequate refrigerating surface and with the temperature of the surface controlled by automatic devices, there should be no humidity problem. When the refrigerating surface is not adequate to maintain the desired atmospheric humidity, pressure-atomized or heat-vaporized water can be added to the air. A system capable of supplying 4 L of water/hour/ton of refrigeration should be able to maintain 95 percent relative humidity under any reasonable conditions (*307, 788*). Up to half of this amount of water may still condense on the cooling surfaces, but the other half provides for absorption by dry containers, walls, ceiling, and floor, if needed. When the demand is less, water sprays or mist can be reduced.

Another method of maintaining high humidity is the jacket system, discussed on p. 21. However, construction and operating costs of jacketed storages are somewhat higher than those for conventional storages. The Filacell system is another effective method which provides good control of temperature and relative humidity in commercial storages (*789*).

Several different devices for measuring relative humidity are available. A common instrument is a psychrometer with two thermometers. The bulb of one thermometer is left uncovered, and the bulb of the other is covered with a wick that has been wetted with distilled water. This wet- and dry-bulb psychrometer works on the principle that if the ambient air is not saturated, water will evaporate from the wet-muslin wick, thereby cooling the wet bulb. The wet bulb drops to a definite temperature when the heat received by convection and conduction from the air flowing over the bulb balances the heat required to evaporate the pure water on the wick. From the difference in temperatures of the wet and dry bulbs, the relative humidity can be determined from slide rules provided with the psychrometer or from psychrometric tables or charts (*43, 585*) (fig. 3). The influence of the atmospheric pressure is insignificant and need not be taken into account for most practical purposes (*789*). Rapid air movement over the thermometers is essential for accurate determinations. This may be effected by swinging the thermometers (sling psychrometer) or, more accurately, by drawing a constant flow of air across the bulbs in an enclosed case. Readings should then be made quickly and carefully. Care should be taken to prevent body heat from influencing the thermometer reading. At temperatures of 0°C and lower, an error of 0.5° in reading either the wet- or dry-bulb thermometer causes an error of 5 to 10 percent in relative humidity (*33, 43*). Carefully calibrated thermometers that read from −4° to 4° in increments of 0.1° are best adapted for this purpose.

Direct readings of relative humidity may be taken with hair hygrometers or gold beater's skin hygrometers. These measurements are based on the principle that organic filaments change length as a function of relative humidity. These devices are relatively inexpensive and not very accurate, especially at high humidity, and they must be checked periodically for accuracy with a psychrometer. Electrical hygrometers are being used increasingly for humidity measurements and to control humidifying equipment. Operation of these is basd on the ability of a hygroscopic film to change its electrical resistance instantly with small changes in relative humidity (*1029*). They must be calibrated periodically. Further discussion on humidity and moisture can be found in several review articles and books (*59, 169, 260, 296, 936, 981, 1028*).

Air Circulation and Package Spacing

Air must be circulated to keep a cold-storage room at an even temperature throughout. Commodity temperatures in a storage room may vary because the air temperature rises as the air passes through the room and absorbs heat from the commodity. There may also be variable heat leakage in various parts of the storage. In a duct system, the air is warmer near the return ducts than near delivery ducts. In many newly constructed storages, refrigeration units are installed over the center aisle, which is desirable. Air circulates from the center of the rooms outward to the walls, down through and between the rows of produce, and back up through the center of the room (*392*).

The need for rapid air circulation is greatest during removal of field heat. Sometimes this heat is best removed in separate precooling rooms that have more refrigerating and air-moving capacity than regular cold-storage rooms. For precooling grapes with air, a minimum volume of 170 m^3 (6,000 ft^3) /minute/1,000 lugs is essential for rapid removal of field heat (*788*).

After field heat has been removed, a high air velocity is unnecessary and usually undesirable. Only enough air movement should be provided to remove respiratory heat and heat entering the room through exterior surfaces and doorways. The air must be directed in such a way that it flows uniformly to all parts of the room. Air movement of 15 to 23 m (50 to 75 lin ft)/minute through the stacks is usually sufficient to accomplish this (*788*).

Usually, air-circulation systems for apple and pear storages are designed to provide for about 28 m^3 (1,000 ft^3) of air/minute/short ton of refrigeration capacity (*697*). For example, a 25-ton plant would circulate about 700 m^3 (25,000 ft^3)/minute.

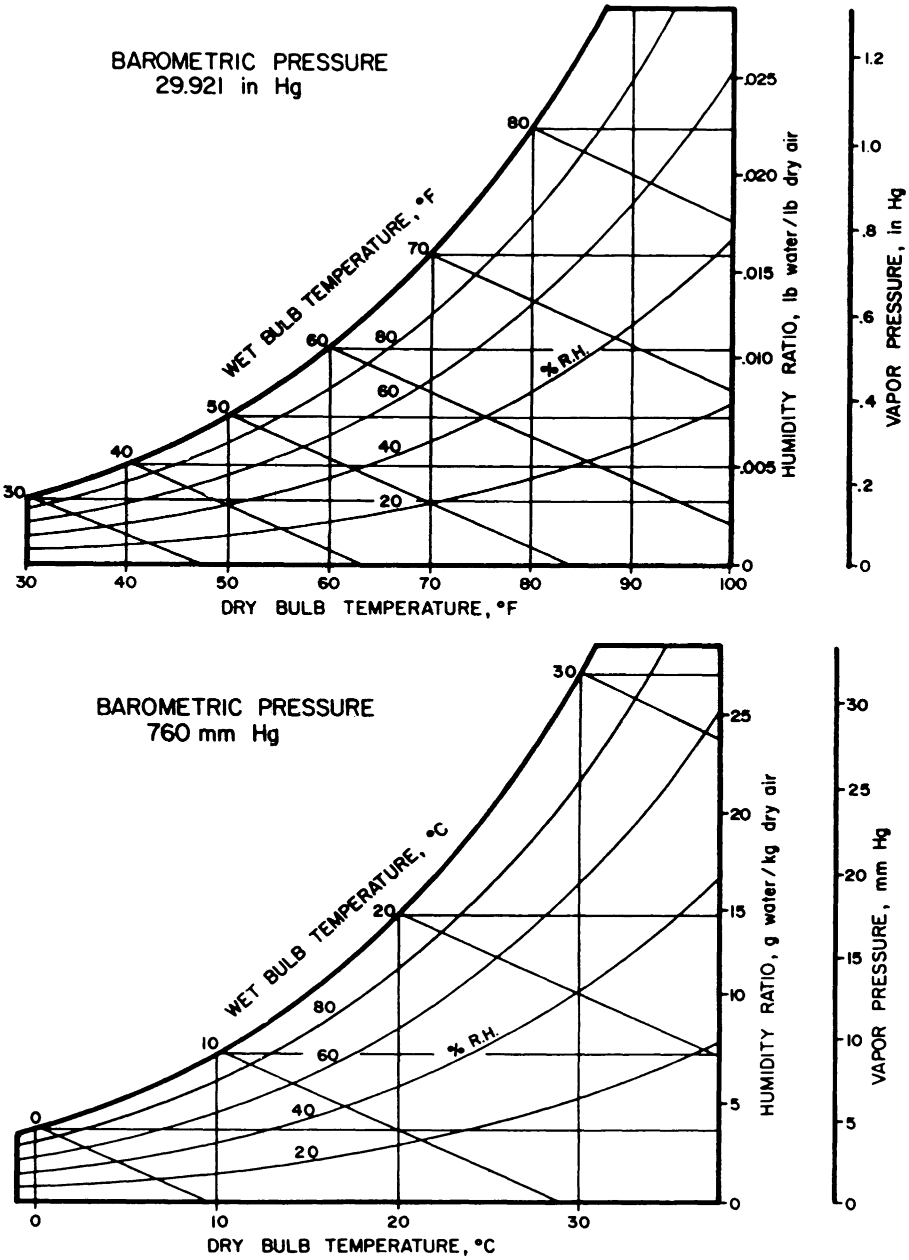


Figure 3
Psychrometric chart for determining percent relative humidity on the basis of wet-bulb and dry-bulb temperatures.

After produce is cooled and temperatures become almost stationary, a split (temperature difference between return and delivery air) exceeding 0.8°C (1.5°F) is an indication of insufficient volume of cold air. Improper adjustment of air-distribution systems was found to be a major cause of nonuniform storage temperatures in apple and pear storage rooms. For maintenance of uniform temperatures, the quantity of air circulated should be sufficient to provide an air-turnover rate of at least 7.5 times per hour in an empty storage (*805*). Modern storage rooms have fans or blowers to provide forced-air circulation, and many systems of distributing air have been developed. (See *247, 697, 788, 805.*)

A question frequently asked is: What effect does rapidly moving air have on weight loss from commodities? The answer to this is closely related to the effect of increased air movement on relative humidity of the air surrounding the product. Rapid circulation of air in a storage does not appreciably increase water loss if the relative humidity is kept high. However, if the humidity is low, commodities in rooms with no circulation show less shriveling. This is because transpiration from the commodity in such rooms causes the humidity of the air adjacent to the product to increase; and hence total water loss diminishes (*504, 715*).

Often packages are piled too closely together or distribution of refrigeration is inadequate to reach all parts of the piles or stacks of the stored commodity. It is not unusual, under such conditions, to have commodities remain for several days or even weeks at temperatures several degrees higher than those indicated by an air thermometer in the aisle. In a good storage, the seasonal average temperature of the warmest produce location should not exceed the coldest by more than 1°C (2°F).

Maintaining constant temperature is usually easier in large rooms than in small ones if both are filled to capacity. The reason is that in large rooms, the large mass of material, including the commodity and the building material, produces a "flywheel" effect that prevents rapid temperature changes. Being deficient in this effect, small storage rooms usually require closer attention than larger ones.

The influence of temperature on the rate of ripening and deterioration has special significance in cold-storage management. For example, some cultivars of apples ripen as much in 1 day at 21°C (70°F) as they do in 10 days at −1° (30°F). Thus, a delay of 3 days in an orchard or warm packing shed may shorten storage life as much as 30 days, even if the apples are then stored at −1°.

The nature of the container and the manner of stacking are important factors that influence cooling rate. An elaborate system for air distribution is useless if poor stacking prevents airflow. A cardinal principle of air movement is that air follows the path of least resistance; thus, if spacing is irregular, the wider spaces get a greater volume of air than the narrower ones. If some spaces are partially blocked, dead air zones occur, with resultant higher temperatures (*697, 788*). Wide aisles in the direction of airflow are undesirable, since much of the air then bypasses the stacked commodities. Generalizations on stacking arrangements are difficult to make because the variety of containers in use for different commodities is large. However, if the same commodity is stored routinely, lines can be painted ont he floor to indicate spacing for rows of containers. A 5- to 7-cm (2- to 3-in) spacing between rows of containers, such as boxes of apples or citrus, is desirable. Rows should be laid out so that the direction of air movement is along the rows rather than across them. A 10- to 20-cm (4- to 8-in) spacing at the sidewalls is desirable so that cold air can be delivered to all levels. Spacing for air circulation at floors and ceiling is also needed, and the top of the stacks of containers should be below the air distribution system (*880*). Pallets and pallet boxes are now widely used (fig. 4). Loaded pallets or pallet boxes should be formed in straight lines to provide approximately 10- to 12-cm (4 to 5 in) of space between rows and to allow forklifts to maneuver (*392, 698*). The channels for forklift trucks on these pallets should all open in the direction of airflow. Most rapid cooling occurs when all sides of pallet boxes are exposed to air movement.

The problems of cooling in relation to stacking arrangement have become more complex with increasing use of pallets, pallet boxes, and corrugated containers. Special precautions should be taken in stacking containers on pallets so that as much container surface as possible is exposed to moving air to expedite cooling. With corrugated containers, the cooling problem may be aggravated because having no bulge or slats, as do many wood containers, they may be stacked too tightly. Produce in unventilated cartons cools very slowly, and often stays appreciably warmer than the surrounding air during storage, unless the product is properly precooled. Ventilation slits in cartons improve cooling, but even more important is proper spacing of containers on pallets (*247, 684*). Moving air past the long sides of each container is desirable for rapid cooling.

Additional information on air circulation, stacking patterns, and spacing for various containers and commodities is available (*101, 697, 698, 789, 805*).

Respiration Rates, Heat Evolution, and Refrigeration

Fresh fruits and vegetables, cut flowers, and similar products are alive and carry on processes characteristic of all living things. The most important of these processes is respiration, by which the oxygen of the air is combined with the carbon of the plant tissue, occurring chiefly in sugars, to form various decomposition products and, eventually, carbon dioxide and water.

$$C_6H_{12}O_6 + 6O_2 \longrightarrow 6\,CO_2 + 6\,H_2O + 673\text{ kcal}$$

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Figure 4
Spacing and stacking arrangements in storage pallet bins (A) and pallet loads (B) of packed cartons of apples.

During this process, energy is released in the form of heat; the amount varies with the commodity and increases as the temperature increases, up to about 38 to 40°C (100 to 104°F). This heat, called vital heat, is always a part of the refrigeration load that must be considered in handling fruits, vegetables, and cut flowers in cold-storage rooms. The approximate rates of heat produced by various commodities at different storage temperatures can be calculated from respiration rates given in table 3.

Heat evolution is expressed in joules in the metric system and in British thermal units (Btu) in the English system. For each milligram of CO_2 produced by respiration, 2.55 cal of heat are generated, so the value of 2.55 is used in computing the heat evolution. One calorie is the amount of heat required to raise the temperature of 1 g of water 1°C, whereas 1 Btu is the amount of heat required to raise the temperature of 1 lb of water 0.56°C (1°F). One calorie equals 4.187 J, so heat evolution in the metric system is computed by multiplying each milligram of CO_2 by a factor of 10.676. The value 10.676 is derived by multiplying 2.55 cal/mg CO_2 by 4.187 J/cal. One kilocalorie equals 3.968 Btu, so heat evolution in British thermal units per ton per day (24 hours) is computed by multiplying the rates of respiration in milligrams of CO_2 per kilogram per hour by a factor of 220. The value 220 is derived by multiplying 2.55 cal/mg CO_2 by 86.3, a factor which converts calories per kilogram per hour to British thermal units per ton per day. Although this method falsely indicates an oversimple respiratory process, heat-of-respiration values calculated by this method agree fairly well with values computed from measurements of O_2 uptake as reported by Haller and others (*325*) and with values determined directly from calorimetric determinations at moderate temperatures up to 26.7°C (80°F) (*290*).

Some products have high respiration rates and, hence, require considerably more refrigeration than more slowly respiring products to keep them at a specified temperature. Asparagus, for example, respires approximately 10 times as fast as tomatoes. Other examples of the variability of respiration and heat production in various commodities are shown in figure 5.

Rate of respiration is governed by temperature. For every 10°C (18°F) rise in temperature, the rate is roughly doubled or tripled. The change in rate with temperature follows van't Hoff's rule fairly closely, which states that the rate of most chemical and biochemical reactions increases two or three times with every 10° rise in temperature. For example, an apple held at 10° ripens and respires about three times as fast as one held at 0°, and one held at 20° respires about three times as fast as one held at 10°. Head lettuce respires about three times as fast at 10° as at 0° and two or three times as fast at 20° as at 10°. The faster a product respires, the greater the quantity of heat generated. Refrigeration is of prime importance in retarding respiration.

The storage life of commodities varies inversely with the rate of respiration. Thus, short-storage cultivars of apples usually have higher rates of respiration than long-storage cultivars (see table 9, p. 32). The storage life of products like broccoli, lettuce, peas, spinach, and sweet corn, which have relatively high rates of respiration, is short; and that of onions, potatoes, and storage cultivars of grapes, which have low respiration rates, is long (table 3).

The respiration rate for a given commodity differs with plant part, cultivar, area of production, growing conditions, and growing season. Consequently, rates of respiration in table 3 are given as a range, as found experimentally. After harvest, the respiration rate of many fruits and vegetables gradually declines as they age in storage. A declining rate is true for asparagus and head lettuce and generally for potatoes (table 4). Some products, such as plums, have a gradually increasing rate of respiration as they ripen after harvest (table 4). Still other products, such as apples, have a respiration rate that increases to a peak (climacteric) and then declines. (See also *33*.)

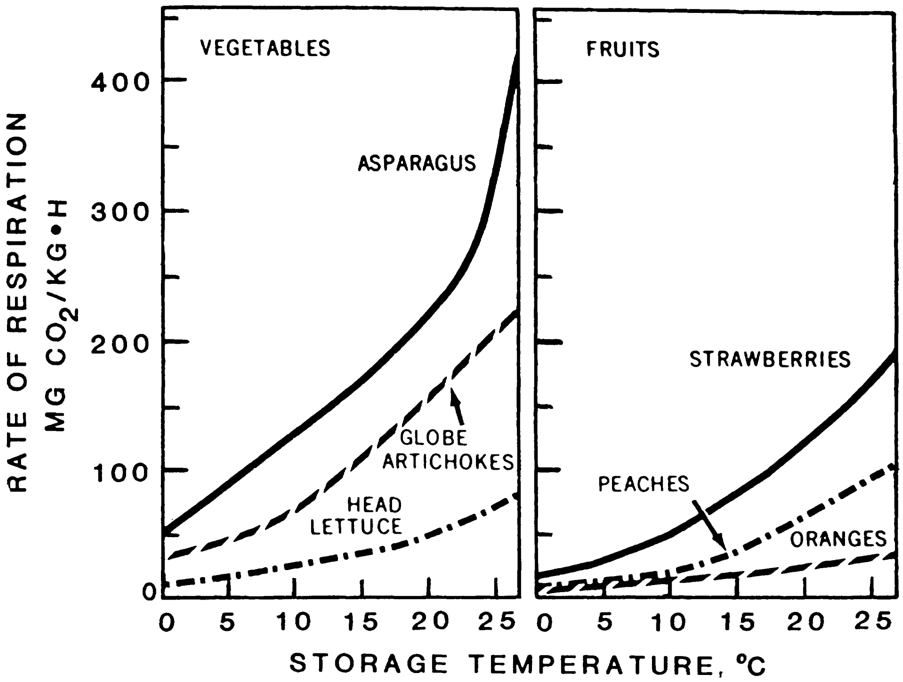

Figure 5
Respiration rates of three fruits and vegetables stored at different temperatures.

Table 3
Respiration rates of fruits and vegetables, expressed as rates of carbon dioxide production (mg/kg•h), at various temperatures[1]

Commodity and source reference	Temperature 0°C (32°F)	4-5°C (40-41°F)	10°C (50°F)	15-16°C (59-60°F)	20-21°C (68-70°F)	25-27°C (77-80°F)
Apples, summer (*857, 882*)	3-6	5-11	14-20	18-31	20-41	—
Apples, fall (*428, 882*)	2-4	5-7	7-10	9-20	15-25	—
Apricots (*158, 356*)	5-6	6-9	11-19	21-34	29-52	—
Artichokes, globe (*751*)	15-45	26-60	55-98	76-145	135-233	145-300
Asparagus (*516*)	27-80	55-136	90-304	160-327	275-500	500-600
Avocados (*87*)	—	20-30	—	62-157	74-347	118-428
Bananas, green[2] (*262*)	—	—	—	21-23	33-35	—
Bananas, ripening (*262, 681*)	—	—	21-39	25-75	33-142	50-245
Beans, lima (*941*)	10-30	20-36	—	100-125	133-179	—
Beans, snap (*1011*)	20	35	58	93	130	193
Bean sprouts (*528*)	21-25	42	93-99	—	—	—
Beets, topped (*857*)	5-7	9-10	12-14	17-23	—	—
Beets, with leaves (*768*)	11	14	22	25	40	—
Berries						
Blackberries (*768, 857*)	18-20	31-41	62	75	[3]155	—
Blueberries[4]	2-10	9-12	23-35	34-62	52-87	78-124
Cranberries[4] (*40*)	—	4-5	—	—	11-18	—
Gooseberries (*428, 861*)	5-7	8-16	12-32	27-69	41-105	—
Raspberries (*324*)	18-25	31-39	28-55	82-101	—	—
Strawberries (*600*)	12-18	16-23	49-95	71-92	102-196	169-211
Broccoli (*817*)	19-21	32-37	75-87	161-186	278-320	—
Brussels sprouts (*558*)	10-30	22-48	63-84	64-136	86-190	—
Cabbage (*817, 977*)	4-6	9-12	17-19	20-32	28-49	49-63
Carrots, topped (*817*)	10-20	13-26	20-42	26-54	46-95	—
Carrots, bunched (*817, 768*)	18-35	25-51	32-62	55-106	87-121	—
Cauliflower (*817*)	16-19	19-22	32-36	43-49	75-86	84-140
Celery (*554, 977*)	5-7	9-11	24	30-37	64	—
Celeriac (*428*)	7	15	25	39	50	—
Cherries, sweet (*270, 623*)	4-5	10-14	—	25-45	28-32	—
Cherries, sour (*356*)	6-13	13	—	27-50	39-50	53-71
Citrus						
Grapefruit (*323, 325, 817*)	—	—	7-9	10-18	13-26	19
Lemons (*323, 325*)	—	—	11	10-23	19-25	20-28
Limes, Tahiti[4]	—	—	—	6-10	7-19	15-45
Oranges (*323, 325, 817*)	2-5	4-7	6-9	13-24	22-34	25-40
Cucumbers (*224*)	—	—	23-29	24-33	14-48	19-55
Endive (*428*)	45	52	73	100	133	200
Figs, fresh (*159*)	—	11-13	22-23	49-63	57-95	85-106
Garlic (*570*)	4-14	9-33	9-10	14-29	13-25	—
Grapes, American (*549*)	3	5	8	16	33	39
Grapes, vinifera (*706*)	1-2	3-6	8	10-12	—	25-30
Kale (*409*)	16-27	34-47	72-84	120-155	186-265	—
Kohlrabi (*713*)	10	16	31	49	—	—
Kiwifruit (*353*)	3	6	12	—	16-22	—
Leeks (*412*)	10-20	20-29	50-70	75-117	110	107-119
Lettuce, head (*648, 817*)	6-17	13-20	21-40	32-45	51-60	73-91
Lettuce, leaf (*817*)	19-27	24-35	32-46	51-74	82-119	120-173
Lychees (*18*)	—	—	—	—	—	75-128
Mangos (*455*)	—	10-22	—	45	75-151	120

See footnotes at end of table.

Table 3
Respiration rates of fruits and vegetables, expressed as rates of carbon dioxide production (mg/kg•h), at various temperatures[1]—Continued

Commodity and source reference	Temperature					
	0°C (32°F)	4-5°C (40-41°F)	10°C (50°F)	15-16°C (59-60°F)	20-21°C (68-70°F)	25-27°C (77-80°F)
Melons						
Cantaloups (*817*)	5-6	9-10	14-16	34-39	45-65	62-71
Honey Dew (*736, 817*)	—	3-5	7-9	12-16	20-27	26-35
Watermelons (*817*)	—	3-4	6-9	—	17-25	—
Mushrooms (*554, 860*)	28-44	71	100	—	264-316	—
Onions, dry (*817*)	3	3-4	7-8	10-11	14-19	27-29
Onions, green (*410*)	10-32	17-39	36-62	66-115	79-178	98-210
Okra (*817*)	—	53-59	86-95	138-153	248-274	328-362
Olives (*598*)	—	—	—	27-66	40-105	56-128
Papayas (*442*)	—	4-6	—	15-22	—	39-88
Parsley (*417*)	30-40	53-76	85-164	144-184	196-225	291-324
Parsnips (*857, 977*)	8-15	9-18	20-26	32-46	—	—
Peaches (*322, 323*)	4-6	6-9	16	33-42	59-102	81-122
Pears, Bartlett (*24, 563*)	3-7	5-10	8-21	15-60	30-70	—
Pears, Kieffer (*553*)	2	—	—	11-24	15-28	20-29
Peas, unshelled (*941*)	30-47	55-76	68-117	179-202	245-361	343-377
Peas, shelled (*941*)	47-75	79-97	—	—	349-556	—
Peppers, sweet (*817*)	—	10	14	23	44	55
Persimmon, Japanese (*280*)	—	6	—	12-14	20-24	29-40
Pineapples, mature-green (*817*)	—	2	4-7	10-16	19-29	28-43
Plums, Wickson (*157*)	2-3	4-9	7-11	12	18-26	28-71
Potatoes, immature[4]	—	12	14-21	14-31	18-45	—
Potatoes, mature[4]	—	3-9	7-10	6-12	8-16	—
Radishes, with tops (*554*)	14-17	19-21	31-36	70-78	124-136	158-193
Radishes, topped (*554*)	3-9	6-13	15-16	22-42	44-58	60-89
Rhubarb, stalk (*407*)	9-13	11-18	25	31-48	40-57	—
Romaine (*817*)	—	18-23	31-40	39-50	60-77	95-121
Rutabagas (*428, 977*)	2-6	5-10	15	11-28	41	—
Spinach (*817*)	19-22	35-58	82-138	134-223	172-287	—
Squash, Butternut[4]	—	—	—	—	—	66-121
Squash, summer (*554*)	12-13	14-19	34-36	75-90	85-97	—
Sweet corn, w/husks (*817, 941*)	30-51	43-83	104-120	151-175	268-311	282-435
Sweetpotatoes, noncured (*554*)	—	—	—	29	—	54-73
Sweetpotatoes, cured[4] (*508*)	—	—	14	20-24	—	—
Tomatoes, mature-green (*817*)	—	5-8	12-18	16-28	28-41	35-51
Tomatoes, ripening (*817, 1058*)	—	—	13-16	24-29	24-44	30-52
Turnips, topped (*817, 857*)	6-9	10	13-19	21-24	24-25	—
Watercress (*417, 857*)	15-26	44-49	91-121	136-205	302-348	348-438

1 Respiration rate often shown as a range. To compute heat evolution rates at harvest time, use either the highest figure or median one. To convert to Btu/ton (2,000 lb)/24-h day, multiply respiration rate by 220. To convert to kcal per 1,000 kg/24 h, multiply by 61.2. Some data included for low temperatures which cause injury to certain commodities or cultivars, such as avocados, mango, okra, papaya, peppers, pineapple, tomatoes and Zucchini squash; these low temperatures are potentially dangerous and should be avoided (see text).

2 At 13° C (55° F) green bananas 14-20 mg CO_2/kg•h.

3 Respiration rate at 18° C (65° F).

4 Sources of unpublished data as follows: R.E. Hardenburg, formerly USDA, Beltsville, MD, data on blueberries and limes; R.C. Wright and T.M. Whiteman, formerly USDA, Beltsville, on cranberries and sweetpotatoes; L.L. Morris, Univ. Calif., Davis, on potatoes and Butternut squash.

Refrigeration is the process of removing heat from a substance; thus, the temperature of the substance is lowered and then maintained at a desired level. Heat is a form of energy possessed by all matter. Cold is merely an expression for a relatively low level of heat. In refrigerated storage, produce is cooled by removing heat from it, not by pumping cold into it. Heat always flows naturally from a warm object to a cooler one. When ice is placed in water the water is cooled because the ice absorbs heat from the water.

Heat is commonly measured in kilojoules (kJ) or in British thermal units (Btu) (p. 10). The ratio of heat required to raise the temperature of a given weight of any other material (such as fruits and vegetables) to that required to cause an equivalent rise in the same weight of water is called its specific heat. It is necessary to know the specific heat of a product to calculate the refrigeration load. It can be estimated from the following equation (*838, 1056*):

$$\text{Specific heat} = 0.008 \times (\text{percent } H_2O \text{ in food}) + 0.20$$

For example, the specific heat of apples, with a moisture content of 84 percent, is 0.008 × 84 + 0.20 = 0.87. The specific heat above freezing for many commodities is given in tables 7 and 13. The water content of many foods is listed in *1015*.

The basic elements of a refrigeration system are refrigerant, compressor, condenser, and evaporator. Ammonia has been the most commonly used refrigerant because of its high capacity of heat absorption. Since it is corrosive and toxic to fruits and vegetables when it leaks out of the refrigeration system, Freon-12 or Freon-22 is used as the refrigerant in some commercial installations. Discussions of the heat from various sources that has to be removed by a refrigeration system and of the mechanics of refrigeration are covered in textbooks (*28, 32, 789, 790, 1059*) and in storage bulletins (*306, 392, 697*). Information on refrigerated transport of produce is also available (*56, 245, 396, 668, 754*).

Table 4
Respiration rate (mg CO_2 produced/kg · h) as affected by storage duration and temperature for several commodities

Commodity and days stored	Temperature 0°C (32°F)	2.5°C (36°F)	5°C (41°F)	10°C (50°F)	15°C (59°F)	20°C (68°F)
Asparagus (Martha Washington)[1]						
1	60	72	105	214	234	269
2	46	58	77	141	180	211
3	39	50	65	118	158	186
4	36	44	57	99	142	174
6	—	—	53	78	116	—
8	32	34	59	70	—	—
Head lettuce (Great Lakes)[2]						
1	17	—	20	40	41	60
5	9	—	13	25	39	56
Potatoes (White Rose)[3]						
2	—	—	6	10	12	16
6	—	—	8	8	8	11
10	—	—	7	7	7	8
Plums (Wickson)[4]						
2	2	3	4	10	12	18
6	2	3	7	9	12	19
18	3	4	9	12	13	—

[1] Data from *516*.
[2] Date from *648*.
[3] Unpublished data from L.L. Morris, Univ. of Calif., Davis.
[4] Data from *157*.

The refrigeration load is commonly referred to in **tons of refrigeration.** This term is a holdover from the days when ice was used. The standard ton of refrigeration is the amount of heat absorbed by a ton of ice melting at 0°C (32°F) in 24 hours. It requires 144 Btu to melt 1 lb of ice at 0°, or 288,000 Btu to melt 1 ton of ice at 0° (144 Btu × 2,000 lb). Since a ton of refrigeration specifies that the ton of ice must be melted in 24 hours, a ton of refrigeration absorbs 288,000 Btu in 24 hours. This is equivalent to 12,000 Btu/hour (12,660 kJ/hour).

The refrigeration requirement of any storage plant must be based on peak refrigeration load. This peak usually occurs when outside temperatures are high and warm produce is being moved into the plant for precooling and storage. The peak refrigeration load depends upon the amount of commodity received each day, the temperature of the commodity at the time it is placed under refrigeration, the specific heat of the commodity, and the final temperature attained.

Refrigerated storage extends the marketable life of most produce, partly because the rates of respiration and metabolism are generally reduced at low temperature. When fruits and vegetables cool, the rate at which they produce heat decreases; therefore, to determine the total amount of heat produced, it is necessary to know the rate of heat production at different temperatures and the length of time the product is in each temperature range.

If the commodity could be cooled to the storage temperature instantaneously, the heat to be removed would be the number of British thermal units obtained by multiplying the specific heat of the product by the difference between the initial and the final temperature and this result multiplied by the weight. This is usually called the sensible heat or field heat. The cooling process, however, requires time; and during this interval additional heat is produced by the respiration

of the stored fruit or vegetable. This heat of respiration is called vital heat.

Other factors affecting the total heat load include heat leakage through room surfaces and open doors and heat produced by electric motors, lights, mechanical handling equipment, and workers.

The following examples in metric units and English units show the factors to be considered in determining the refrigeration required for a cold-storage plant. The examples have been simplified to illustrate the steps necessary to calculate the heat load of a refrigerated storage during cooling and normal storage operation. More complete information on load calculations are found in *32, 71, 697, 789.* A series of equations for load calculations that can be solved with personal computers are available (*71*).

Example in metric units: pear storage at −1.1°C

Conditions

Storage size	15 × 15 × 4.5 m
Outside surface area, including floor	720 m^2
Inside dimensions	14.7 × 14.7 × 4.2 m
Volume	908 m^3
Insulation	7.6 cm of polyurethane, with conductivity value (k) = 1.3 $kJ/m^2/cm$ thickness/°C Coefficient of transmission (U) = 1.1 $kJ/h/m^2/°C$
Ambient conditions at harvest	30°C and 50 percent relative humidity (RH)
Fruit temperature	At harvest, 21°C In storage, −1.1°C
Storage capacity	600 bins at 500 kg fruit/bin = 300,000 kg of fruit
Bin weight	63.5 kg Total weight of bins, 38,100 kg
Loading rate	200 bins, or 100,000 kg fruit/day; 3 days to fill
Cooling rate	First day, 21° to 4.5°C Second day, 4.5° to −1.1°C
Air changes due to door openings during cooling	Six per day
Air changes due to door openings during storage	1.8 per day
Specific heat (sp. ht.)	Pears, 0.86 Wood bins, 0.5
Heat load in lowering air at 30°C and 50 percent RH to −1.1°C	74.5 kJ/m^3
Heat load in lowering air from 7.2°F and 70 percent RH to −1.1°C	15.3 kJ/m^3
Miscellaneous heat loads	Lights, 2,400 w/h Fans, 3 hp Two electric forklift trucks, 36,920 kJ each for 8 h Two men working 8 h, 1,000 kJ/h each

A. Load during cooling and filling storage (Temperature difference (TD) = 30°C to −1.1°C = 31.1°C; assume 31.1°C TD on all surfaces.)	**kJ/24 h**
1. Building-transmission load:	
Area (720 m^2) × U (1.1 kJ) × TD (31.1°C) × hours (24) =	591,149
2. Air-change load from door openings:	
Volume (908 m^3) × heat load (74.5 kJ) × air changes (6) =	405,876
3. Product load:	
a. Product cooling (field heat, or sensible heat, removal)—	
First day	
Fruit wt. (100,000 kg) × sp. ht. (0.86) × TD(21° to 4.5°C) × kJ factor (4.186) =	5,939,934
Bin wt. (12,700 kg) × sp. ht. (0.5) × TD (21° to 4.5°C) × kJ factor (4.186) =	438,588
Second day	
Fruit wt. (100,000 kg) × sp. ht. (0.86) × TD (4.5° to −1.1°C) × kJ factor (4.186) =	2,015,977
Bin wt. (12,700 kg) × sp. ht. (0.5) × TD (4.5° to −1.1°C) × kJ factor (4.186) =	148,854
b. Heat of respiration during cooling (vital heat)—	
First day	
(Av. temp., 13°C; resp. rate, 12,206 kJ/t/24 h.) Tonne of fruit (100) × rate (12,206) =	1,220,600
Second day	
(Av. temp., 1.7°C; resp. rate, 1,741 kJ/t/24 h.) Tonne of fruit (100) × rate (1,741) =	174,100
Maximum accumulated in storage before cooling completed	
(Total fruit wt. (300,000 kg) − 2 days' loading wt. (200,000 kg) = 100,000 kg, or 100 t; resp. rate at −1.1°C, 812 kJ/t/24 h.) Tonne of fruit (100) × rate (812) =	81,200
4. Miscellaneous heat loads:	
Lights—watts (2,400) × kJ per watt (3.6) × hours (8) =	69,120
Fans—hp (3) × kJ per hp (3,112) × hours (24) =	224,064
Forklifts—2 × 36,920 kJ per forklift for 8 h =	73,840
Labor—men (2) × kJ per hour (1,000) × hours (8) =	16,000
5. Total heat load during cooling:	
Building transmission	591,149
Air change	405,876
Product cooling	8,543,353
Production respiration	1,475,900
Miscellaneous	383,024
Subtotal	11,399,302
Add 10 percent for safety	1,139,930
Total required refrigeration	12,539,232

Assuming that refrigeration equipment operates 18 hours a day,
12,539,232 ÷ 18 = 696,624 kJ/h
Since a ton of refrigeration absorbs 12,660 kJ/24 h,
696,624 ÷ 12,660 = 55 tons of refrigeration capacity.
This represents the peak capacity required.

B. Load during normal storage operation
(Av. outside ambient conditions, 7.2°C at 70 percent RH; storage temperature, −1.1°C; TD = 7.2° to −1.1°C = 8.3°C.)

	kJ/24 h
1. Building-transmission load:	
Area (720 m^2) × U (1.1 kJ) × TD (8.3°C) × hours (24) =	157,766
2. Air-change load from door openings:	
Volume (908 m^3) × heat load (15.3 kJ) × air changes (1.8) =	25,006
3. Product load (fruit respiration), no cooling:	
(Respiration rate at −1.1°C, 812 kJ/t/24 h.)	
Tonne of fruit (300) × rate (812) =	243,600
4. Miscellaneous heat loads:	
Lights—watts (2,400) × kJ per watt (3.6) × hours (4) =	34,560
Fans—hp (3) × kJ per hp (3,112) × hours (24) =	224,064
Labor—men (1) × kJ per hour (1,000) × hours (4) =	4,000
5. Total load during storage:	
Building transmission	157,766
Air change	25,006
Product load (respiration)	243,600
Miscellaneous	262,624
Subtotal	688,996
Add 10 percent for safety	68,899
Total required refrigeration	757,895

Assuming that refrigeration equipment operates 18 hours a day,
757,895 ÷ by 18 = 42,105 kJ/h,
42,105 ÷ 12,660 = 3.3 tons of refrigeration capacity during normal storage.

Example in English units: pear storage at 30°F

Conditions

Storage size	50 × 50 × 15 ft
Outside surface area, including floor	8,000 ft^2
Inside dimensions	49 × 49 × 14 ft
Volume	33,614 ft^3
Insulation	3 inches of polyurethane, with conductivity value (k) = 0.16 Btu/ft^2/inch thickness/°F Coefficient of transmission (U) = 0.0534 Btu/h/ft^2/°F
Ambient conditions at harvest	85°F and 50 percent relative humidity (RH)
Fruit temperature	At harvest, 70°F In storage, 30°F
Storage capacity	600 bins at 1,100 lb fruit/bin = 660,000 lb of fruit
Bin weight	140 lb Total weight of bins, 84,000 lb
Loading rate	200 bins, or 220,000 lb fruit/day; 3 days to fill
Cooling rate	First day, 70° to 40°F Second day, 40° to 30°F
Air changes due to door openings during cooling	Six per day
Air changes due to door openings during storage	1.8 per day
Specific heat (sp. ht.)	Pears, 0.86 Wood bins, 0.5
Heat load in lowering air at 85°F and 50 percent RH to 30°F	2.0 Btu/ft^3
Heat load in lowering air from 45°F and 70 percent RH to 30°F	0.41 Btu/ft^3
Miscellaneous heat loads	Lights, 2,400 w/h Fans, 3 hp Two electric forklift trucks, 35,000 Btu each for 8 h Two men working 8 h, 950 Btu/h each

A. Load during cooling and filling storage (Temperature difference (TD) = 85°F to 30°F = 55°F; assume 55°F TD on all surfaces.)

	Btu/24 h
1. Building-transmission load: Area (8,000 ft^2) × U (0.0534 Btu) × TD (55°F) × hours (24) =	563,904
2. Air-change load from door openings: Volume (33,614 ft^3) × heat load (2.0 Btu) × air changes (6) =	403,368

3. Product load:
   a. Product cooling (field heat, or sensible heat, removal)—

	Btu/24 h
First day	
Fruit wt. (220,000 lb) × sp. ht. (0.86) × TD(70° to 40°F) =	5,676,000
Bin wt. (28,000 lb) × sp. ht. (0.5) × TD (70° to 40°F) =	420,000
Second day	
Fruit wt. (220,000 lb) × sp. ht. (0.86) × TD 40° to 30°F) =	1,892,000
Bin wt. (28,000 lb) × sp. ht. (0.5) × TD (40° to 30°F) =	140,000

   b. Heat of respiration during cooling (vital heat)—

First day (Av. temp., 55°F; resp. rate, 10,500 Btu/ton/24 h.) Tons of fruit (110) × rate (10,500) =	1,155,000
Second day (Av. temp., 35°F; resp. rate, 1,500 Btu/ton/24 h.) Tons of fruit (110) × rate (1,500) =	165,000
Maximum accumulated in storage before cooling completed (Total fruit wt. (660,000 lb) − 2 days' loading wt. (440,000 lb) = 220,000 lb, or 110 tons; resp. rate at 30°F, 700 Btu/ton/24 h.) Tons of fruit (110) × rate (700) =	77,000

4. Miscellaneous heat loads:

Lights—watts (2,400) × Btu per watt (3.42) × hours (8) =	65,664
Fans—hp (3) × Btu per hp (2,950) × hours (24) =	212,400
Forklifts—2 × 35,000 Btu per forklift for 8 h =	70,000
Labor—men (2) × Btu per hour (950) × hours (8) =	15,200

5. Total heat load during cooling:

Building transmission	563,904
Air change	403,368
Product cooling	8,128,000
Product respiration	1,397,000
Miscellaneous	363,264
Subtotal	10,855,536
Add 10 percent for safety	1,085,554
Total required refrigeration	11,941,090

Assuming that refrigeration equipment operates 18 hours a day,
   11,941,090 ÷ 18 = 663,393 Btu/h
Since a ton of refrigeration absorbs 288,000 Btu/24 h or 12,000 Btu/h,
   663,393 ÷ 12,000 = 55 tons of refrigeration capacity.
   This represents the peak capacity required.

B. Load during normal storage operation
(Av. outside ambient conditions, 45°F at 70 percent RH; storage temperature, 30°F; TD = 45° to 30°F = 15°F.)

	Btu/24 h
1. Building-transmission load:	
Area (8,000 ft^2) × U (0.0534 Btu) × TD (15°F) × hours (24) =	153,792
2. Air-change load from door openings:	
Volume (33,614 ft^3) × heat load (0.41 Btu) × air changes (1.8) =	24,807
3. Product load (fruit respiration), no cooling:	
(Respiration rate at 30°F, 700 Btu/ton/24 h.)	
Tons of fruit (330) × rate (700) =	231,000
4. Miscellaneous heat loads:	
Lights—watts (2,400) × Btu per watt (3.42) × hours (4) =	32,832
Fans—hp (3) × Btu per hp (2,950) × hours (24) =	212,400
Labor—men (1) × Btu per hour (950) × hours (4) =	3,800
5. Total load during storage:	
Building transmission	153,792
Air change	24,807
Product load (respiration)	231,000
Miscellaneous	249,032
Subtotal	658,631
Add 10 percent for safety	65,863
Total required refrigeration	724,494

Assuming that refrigeration equipment operates 18 hours a day,
724,494 ÷ 18 = 40,250 Btu/h
Since a ton of refrigeration absorbs 12,000 Btu/h,
40,250 ÷ 12,000 = 3.35 tons of refrigeration capacity during normal storage.

Weight Loss in Storage

Loss of water from harvested horticultural crops is a major cause of deterioration in storage. Most fruits and vegetables contain between 80 and 95 percent water by weight, some of which may be lost by evaporation. This loss of water from living tissues is known as **transpiration.** The rate of transpiration, which must be minimized to avoid loss in salable weight and avoid wilting and shriveling of produce, can be controlled by good handling conditions at recommended humidity and temperature. Some weight loss is due to loss of carbon in respiration, but this is only a minor part of the total. For example, for apples stored at 3.0°C (37°F), loss of weight due to respiration is about 0.05 percent/week, whereas that due to transpiration is about 0.5 percent/week (*1040*). Water loss results not only in appreciable weight loss but also in less attractive produce of poorer texture and lowered quality. The vitamin C content of green vegetables decreases more readily when they are stored under conditions favorable to wilting than conditions not favorable to wilting (*234*).

The rate of transpiration can be reduced by raising the relative humidity, by lowering the air temperature, by reducing air movement, and by protective packaging. The optimum relative humidity for storage of most horticultural crops is between 90 and 100 percent, as discussed under the section on relative humidity. Water loss is faster at a high temperature than at a low one when the relative humidity is the same. Stated another way, identical relative humidities at different temperatures represent quite different drying powers. (See *161, 162, 715, 722, 854, 1021.*)

All fruits, vegetables, and nursery stock do not lose water at the same rate when stored under the same conditions. The rate of loss differs with the type of protective tissue on the exposed surface and with the area of exposed surface per unit volume. Leafy vegetables, such as celery and lettuce, tend to lose water at a rapid rate, whereas melons, apples, and squash, with less surface exposed, lose water slowly. The thickness and nature of the protective waxy coating is also highly variable. Carrots have less protective waxy covering than most apples or pears and consequently lose water faster. Roots stored with the tops attached lose water much faster than those with tops removed. Tomatoes have a relatively impermeable skin but can lose water readily through the stem scar.

Relatively little information is available on rates of moisture loss from different fruits and vegetables under commercial storage conditions. Moisture losses of 3 to 6 percent are enough to cause a marked loss of quality for many types of produce. A few commodities may lose 10 percent or more in moisture and still be marketable, although some trimming may be necessary, as for stored cabbage (*411*). Shrinkage per day for several vegetables held at 27°C (80°F) and 60 percent relative humidity—very adverse conditions—are as follows: Asparagus, 8.4 percent; snap beans, 4.0 percent; topped carrots, 3.6 percent; rutabagas, 3.2 percent; topped beets, 3.1 percent; cucumbers, 2.5 percent; summer squash, 2.2 percent; tomatoes, 0.9 percent; winter squash, 0.3 percent (unpublished data of H. Platenius, Cornell University, Ithaca, NY). Relative rates of moisture loss under storage conditions for other vegetables (*161, 722*), fruits (*26, 153, 844, 1021*), and nursery stock (*566*) have been published.

Water vapor, like other gases, moves from a region of high concentration to a region of low concentration. The relative humidity of the in-

ternal atmosphere of nearly all fruits, vegetables, and flowers is at least 99 percent; that of the surrounding atmosphere, usually less. Hence, if products are held in an atmosphere with a relative humidity of less than 99 percent, they will release water vapor from their tissues into the atmosphere, that is, transpire. The drier the storage air, the more rapid the loss of water from stored products. As long as there is a difference between the surrounding and internal vapor pressures, transpiration, or evaporation, will continue. This difference in vapor pressure is called the vapor-pressure deficit.

Water loss generally is highest during the first few hours or days in storage, while the produce is still cooling. For example, if 20°C carrots are placed in a 0° room and if the relative humidity of the room and the intercellular spaces of the vegetable is 100 percent, the vapor pressures will be 17.54 mm of mercury (Hg) for the carrots and 4.58 mm Hg for the room (table 5). Water vapor moves from the warm stored product into the air even though the relative humidity of the storage is 100 percent. The vapor-pressure deficit in this case is much greater than that between relative humidities of 100 and 50 percent at a temperature of 0°:

	Relative humidity (percent)	Vapor pressure (mm Hg)
Vegetables at 20°C	100	17.54
Air at 0°C	100	4.58
Vapor-pressure deficit		12.96
Vegetables at 0°C	100	4.58
Air at 0°C	50	2.29
Vapor-pressure deficit		2.29

These relationships emphasize the importance of prompt cooling in storage or, preferably, precooling before storage. The longer it takes to lower the temperature of the product to that of the storage, the greater will be the moisture loss.

Table 5
Relation of temperature and relative humidity to the vapor pressure of water and the vapor-pressure deficit[1]

Temperature and percent relative humidity	Vapor pressure (mm Hg)	Vapor-pressure deficit (mm Hg)
0°C (32°F) and—		
100	4.58	0
90	4.12	.46
70	3.21	1.37
50	2.29	2.29
3°C (37°F) and—		
100	5.69	0
90	5.12	.57
70	3.98	1.71
50	2.84	2.85
5°C (41°F) and—		
100	6.54	0
90	5.89	.65
70	4.58	1.96
50	3.27	3.27
10°C (50°F) and—		
100	9.21	0
90	8.29	.92
70	6.45	2.76
50	4.60	4.61
20°C (68°F) and—		
100	17.54	0
90	15.79	1.75
70	12.28	5.26
50	8.77	8.77

[1] At 762 mm barometric pressure.

The following is another example of the effect of temperature on vapor pressure. Moisture loss usually will be more rapid from apples stored at 3°C than at 0° if the relative humidity of both rooms is 90 percent, because the vapor-pressure deficit is greater at 3°. In this example the difference in vapor-pressure deficits is not large; however, as the storage temperature is increased, the amount of water vapor the air will hold at saturation increases fairly rapidly. Thus, relative humidity control becomes even more important at warm than at cold storage temperatures.

	Relative humidity (percent)	Vapor pressure (mm Hg)
Fruit at 3°C	100	5.69
Air at 3°C	90	5.12
Vapor-pressure deficit		.57
Fruit at 0°C	100	4.58
Air at 0°C	90	4.12
Vapor-pressure deficit		.46

Further examples of temperature and relative humidity relationships on moisture loss are found in references (*197, 348, 411, 502, 567, 568, 569, 788, 884*).

Loss of moisture can often be minimized with protective packaging to supplement the benefits of refrigeration and high humidity. Plastic materials, such as polyethylene film, can be used for consumer-size packaging or for box liners, pallet covers, or tarpaulins to protect stored commodities. When plastic materials are used, the following two factors should be kept in mind: (1) Films may restrict the transfer of carbon dioxide and oxygen as well as water vapor and thus cause the carbon dioxide to accumulate or the oxygen to be lowered to a harmful concentration and (2) films restrict the transfer of heat out of the container, which retards the rate of cooling (*805*). Film box liners are used commercially for pears, sweet cherries, Golden Delicious apples, and nursery stock (*205, 269, 338, 566, 973, 1062*).

Considerable moisture may be lost from produce to dry wooden or corrugated fiberboard containers. For example, a 4.5- to 5-kg (10- to 11-lb) dry field crate packed with apples may gain from 0.3 to 0.4 kg in weight during a storage season; most of the moisture would be taken from the apples. Sometimes, wooden boxes are moistened in advance to reduce such losses. Fiberboard containers can be coated or impregnated with wax or polyethylene to inhibit absorption of moisture from the produce (*162, 567, 714, 845*).

The jacketed system of cold storage is used to some extent in Canada and abroad as a means to attain 97–100 percent relative humidity, which minimizes moisture loss and lowers the incidence of decay (*443, 505, 975, 981*). In this system, the room is cooled by air that circulates from an evaporator in one end wall through a jacket, or envelope, surrounding the room. Heat leaking into the room insulation is absorbed by the flowing refrigerated air in the jacket. Advantages of the jacketed system are that (1) high relative humidity, approaching 100 percent, can be maintained easily, so weight losses are low; (2) condensation of water vapor in the insulation of the room is prevented; and (3) frost formation on refrigerated coils is reduced. Disadvantages are that (1) the construction cost is high; (2) precooling is not feasible unless the room is designed so that the refrigerated air can bypass the jacket during precooling; (3) removal of the heat of respiration, which is relatively small in relation to sensible heat, is more difficult; and (4) condensation drips from the ceiling and walls unless the room is designed appropriately.

Sanitation and Air Purification

Maintenance of sanitary conditions within storage rooms is essential for minimizing development of and contamination by decay organisms. During several months' operation of a storage, even at −0.5°C (31°F), molds grow on the surface of packages and on the walls and ceiling of rooms under high relative humidity conditions. These surface molds generally do not rot fruits and vegetables, but they can have an undesirable effect by producing ethylene and other volatiles that hasten senescence and give off-flavors to produce. In addition, areas with surface molds are conducive to growth of rot causing organisms. Hence, old and contaminated containers and storage warehouses should have a thorough cleaning at least once a year. Good air circulation alone is of considerable value in minimizing growth of surface molds (*883*).

Horticultural products may become infected during grading and packing before or after storage. This possibility is especially great if decay is present in the commodity and if moisture condenses on the packed product. Sanitary precautions should be taken in handling decayed material. Rotting fruits and vegetables should be handled carefully to avoid spreading spores; and, once removed from the container, rotting produce should be disposed of promptly.

Questions are raised about the usefulness of ozone in storage rooms to control mold. Ozone has been recommended to reduce growth of surface mold on walls and containers, to reduce mold spore count in the air, and to reduce storage odors (*232, 886*). It is not effective in controlling decay. (See "Supplements to Refrigeration" for additional information on ozone.)

A complete storage cleanup should be done when rooms are empty and well in advance of the next loading date. The floors should be cleaned of all debris and scrubbed. A practical way to clean the ceiling and walls is to apply whitewash as a spray. If floors and walls become moldy, they may be scrubbed with a cleaner containing sodium hypochlorite or trisodium phosphate; then they should be rinsed, and the room aired. Added protection can be obtained by using fungicidal paint. Field boxes and equipment can be cleaned with 0.25 percent calcium hypochlorite solutions or by 2 minutes of exposure to superheated steam. In some regions, storage rooms are fumigated with a mixture of 85 percent carbon dioxide and 15 percent ethylene (*594*).

Air purification is a recommended practice in storage rooms where odors or volatiles may contribute to off-flavors and hasten deterioration (*32, 271, 272, 771, 926, 974*). Usually air purification involves using trays or canisters of 6- to 14-mesh activated coconut-shell carbon. During ripening, fruits and vegetables produce volatile organic substances that escape into the storage atmosphere. Some are pleasant, such as varietal aromas; others are unpleasant or may contribute to deterioration and storage disorders. Some fruit volatiles are removed by air purification, but ethylene, a ripening gas, is not removed by activated carbon alone. Experimental results on the value of air purification in retarding fruit ripening and storage disorders, such as apple scald, are contradictory. Chemical treatments for scald control are far more reliable. The primary value of air purification is odor removal. Pine wood volatiles are one type known to be removed by activated-carbon air-purifying units.

Washing the air with water to remove volatiles, a practice in some European countries, does not retard fruit ripening but can increase the relative humidity and thereby aid in maintaining good fruit appearance by reducing weight loss (*122, 331*).

Supplements to Refrigeration

Although refrigeration is the most effective method of retarding spoilage of most horticultural crops, supplemental treatments are often beneficial for certain crops. Supplements can be used to control decay and thus lengthen the storage life; to retard respiration, particularly when the crop has to be stored at moderate temperatures; to control physiological disorders and sprouting; or to control moisture loss. It should be remembered that supplements are, as the name indicates, supplements and not substitutes for proper refrigeration and careful handling. When supplements are used, they are discussed briefly under each commodity. Safer and more effective supplements are continually being developed. Users of supplements should, therefore, keep in touch with their State experiment station or Extension Service or the U.S. Department of Agriculture for the latest information.

Chemical Treatments and Fumigation

Fruits and vegetables are frequently cleaned, cooled, and conveyed in water, as well as treated with aqueous formulations of chemicals after harvest. Familiar examples are washing citrus fruit, apples, and potatoes; hydrocooling peaches; and applying antiscald materials to apples before storage. Often the water is recycled for extended periods and becomes heavily contaminated with propagules of pathogenic fungi and bacteria unless an effective concentration of antimicrobial agent is maintained in the water (*229*). Low concentrations of chlorine (50 to 100 p/m) are often used in wash water, soak tanks, or hydrocoolers to reduce the number of micro-organisms in the water. Such concentrations control only the buildup of bacteria and fungi in the water, they do not inhibit growth of organisms already established on the product (*865*). In some cases, the chlorine is used in the form of hypochlorite solutions and in other cases as chloramines. Chlorine solutions are also useful in cleaning packing house belts, rollers, and other equipment. Sodium *o*-phenylphenate (SOPP), used with detergents, also has been helpful in removing spores from fruit and reducing the spore load in the wash water.

Antioxidants, such as butylated hydroxyanisole (BHA), are used to retard development of rancidity of shelled nuts. Diphenylamine and ethoxyquin usually give good control of storage scald on apples and Anjou pears.

Growth regulators are used to control sprouting of potatoes and onions during storage. These include maleic hydrazide, isopropyl *N*-(3-chlorophenyl) carbamate (CIPC), nonyl alcohol, and the methyl ester of naphthalene acetic acid (MENA). Most lemons grown in California are treated with 2,4-dichlorophenoxy acetic acid (2,4-D) before storage to delay alternaria rot and senescence of the button (calyx). Calcium chloride, which might be considered a senescence inhibitor, is used in postharvest treatments to control bitter pit in apples, retard storage breakdown, and help maintain firmness in some apple cultivars.

Among the fumigation treatments, use of sulfur dioxide is a standard practice to control decay of vinifera grapes. Sulfur dioxide also retards respiration and preserves the fresh color of stems (*790*). Biphenyl is impregnated into paper pads or fruit wraps and used to control decay in packages of some citrus fruits. Biphenyl inhibits sporulation of *Penicillium* on decaying fruit and thus prevents soilage of adjacent fruit by mold spores. Some fruits and vegetables from foreign countries or to be exported to another country must be fumigated to prevent the spread of various insects. Ethylene dibromide (EDB) and methyl bromide (MB) were in wide use for disinfestation and control of insects, but their use for some of these applications is now banned. Each must be used under carefully controlled conditions to assure control of insects and to avoid injury to the product being treated. Specific treatments are needed for each situation.

Ozone is of little, if any, value in controlling decay of fruits and vegetables in storage. Concentrations as low as 0.5 p/m injure lettuce and strawberries, and 1.0 p/m injures peaches (*895*). Low concentrations of ozone can also be harmful to humans.

Fungicides and bactericides that effectively reduce decay are beneficial supplements to produce during refrigerated storage. Fungicides are often applied in conjunction with a cleaning, brushing, or waxing operation. Important fungicides include benomyl, thiabendazole (TBZ), 2,6-dichloro-4-nitroaniline (DCNA), 2-aminobutane, SOPP, and imazalil. The application of TBZ and benomyl to treat postharvest diseases of citrus, apples, bananas, and stone fruits represented a major advance in the storage and handling of these crops. New more effective chemicals for decay control are continually being developed.

Ethylene gas is used both to hasten or initiate ripening of tomatoes, some melons, and bananas and to degreen some kinds of citrus. In other situations, ethylene may be harmful, and filters containing an ethylene absorbent, such as potassium permanganate, are needed to remove it.

Chemicals used in preservative solutions for cut flowers are discussed later in this handbook.

Several factors must be considered before a chemical treatment is used: it must be effective for the purpose for which it is intended; it must be reasonable in cost; it must not be toxic to the commodity; and, most important of all, it must not be harmful to humans. Only chemicals that have been registered for the particular crop and use and approved by the Food and Drug Administration must be used. They should be used only when necessary and not indiscriminately. They should be used only as described on the label. (See also *33, 789*.)

Controlled- and Modified-Atmosphere Storages

Controlled-atmosphere (CA) storage is a technique for maintaining the quality of produce in an atmosphere that differs from air in respect to the proportion of oxygen (O_2), carbon dioxide (CO_2), or nitrogen (N_2). The desired composition of the atmosphere for storing commodities may be obtained by adding or scrubbing O_2 or CO_2 in a tight storage room or container.

The term "modified-atmosphere storage" (MA storage) is sometimes used synonymously with CA storage. More accurately, however, it refers to storage of produce in an atmosphere that is different from air but not controlled precisely. The atmosphere surrounding stored produce packed in plastic film is an example, its composition being determined by several factors: the rate of respiration of the produce, any addition of gas mixtures to the package, the permeability of the film, the storage temperature, and the tightness of the container.

Although the use of CA storage was first reported by Kidd and West (*467*) in England over 60 years ago, the practice did not get started in the United States on a commercial basis until the early forties, with McIntosh apples in the Hudson Valley (*429, 877, 967*). Because of its effectiveness in extending the storage life of apples and pears, the commercial use of CA storage, mainly for apples, has increased steadily, especially since 1960, with the use of atmosphere generators and improved carbon dioxide scrubbers. Progress in the development of CA techniques and equipment has been significant during the past decade, both for science and industry (*99*). The commercial application of CA during transportation has also received considerable interest (*448*). Several conferences on CA research and applications have been held (*200, 203, 760*), and bibliographies of the literature on CA and MA storage have been compiled (*449, 450, 643, 654*).

Several types of CA storage have shown beneficial effects, particularly for maintaining the quality of apples and pears. These include regular CA, rapid CA, low-oxygen CA, low-ethylene CA, short-term high-CO_2 treatment, carbon monoxide storage, and low-pressure or hypobaric storage. (See "Apples" for further details.) Research has shown that applications of CA storage for commodities other than apples and pears appear to be promising. When beneficial effects of CA storage have been shown, they will be discussed under individual commodities.

Waxing and Surface Coatings

The application of wax or wax emulsion coatings to certain perishable products has been practiced for many years. This practice probably started with the waxing of citrus fruits (*82, 316, 335*); the waxing of rutabagas and turnips followed (*254, 355, 721*). Much research on waxing deciduous fruits has been done, but waxing of these fruits has received little commercial use, except for apples and more recently peaches and nectarines (*156, 821, 875*). Waxes are used commercially rather extensively on oranges, grapefruit and other citrus, apples, rutabagas, turnips, mature-green tomatoes, peppers, cucumbers, sweet potatoes, cantaloups, and melons and to a limited extent on parsnips, eggplants, carrots, small summer squashes, papayas, and mangos. With products such as citrus, cucumbers, and root crops, waxing reduces moisture loss and, thus, retards shriveling (*721, 826*). With some products, an improved glossy appearance is the main advantage. Waxed apples take on a bright lustrous finish which is retained during extended storage (*821, 875*). Often, the thickness of wax coatings is critical. Too thin a coating may give little if any protection against moisture loss; too heavy a coating may increase decay and breakdown. Waxing is not recommended for potatoes, leafy vegetables, or bunched root crops (*721*). Rutabagas or lemons should not be waxed before extended storage but, rather, just before marketing for protection and improved appearance (*254*).

We emphasize that waxing does not improve the quality of any inferior horticultural product but that it can be a beneficial adjunct to good handling. Wax formulations by themselves do not control decay, as is sometimes claimed; but combined with fungicides in a single application, they can be valuable in retarding deterioration. Wax coatings are also sometimes used as carriers for sprout inhibitors, other growth regulators, and preservatives.

Some types of nursery stock keep better in storage and during marketing after receiving a wax coating. Dormant rose plants are an example (*625, 957*).

Application methods include spraying with or dipping into water emulsions, foaming, fogging with solutions made with volatile solvents, dripping emulsions onto rotating brushes, and using brushes that are first brushed against solid cake waxes. After application, the products usually are dried with heated air and polished with rotating brushes. Uniformity of coverage is important for succes. The type of applicator used is the single most important factor in uniform application of a wax coating (*316*). All coatings on fruits and vegetables must meet the food additives regulations of the Federal Food and Drug Administration.

At least four types of waxes are used. **Solvent waxes,** widely used on citrus, are composed of 70 to 80 percent aliphatic hydrocarbons, up to 25 percent aromatic hydrocarbons, and a solvent such as acetone or ethyl acetate. This solvent will contain either a synthetic resin or a natural wood rosin plus one or more plasticizers. **Water waxes** are a second major type, the most extensively used being resin solution waxes and emulsion waxes. Resin solution waxes are simply solutions of one or more alkali-soluble resins or resin-like materials, such as shellac, protein natural gums, or wood rosin. Emulsion waxes are composed of a natural wax (such as carnauba or paraffin) or a synthetic wax (such as polyethylene emulsion) in a soap or detergent. **Bar** or **slab waxes** are composed of mixtures of waxes cast into bars. These waxes are mostly based on paraffin, with small amounts of other waxes included. **Paste/oil waxes** are mainly composed of paraffins that are dif-

ferent in melting point and blended to give a desired viscosity. These waxes, often used on vegetables, are dripped on an overhead brush, which then brushes the wax onto the produce (*316*).

More extensive details of waxing research are found in references *156, 335, 355, 625, 721, 821, 826*.

Irradiation

The use of gamma radiation has been studied for controlling decay, disinfestation, and extending the storage and shelf life of fresh fruits and vegetables. Dosages of 1.5 to 2 kilogray (kGy), and in some cases 3.0 kGy (300 krad), have been effective in controlling decay in several products (*84, 85, 86, 649*). However, dosages of 1.5 kGy and above can cause discoloration, pitting, softening, abnormal ripening, or flavor loss (*195*). Of 22 fruits and vegetables tested (*108, 109*) only 3—strawberries, mushrooms, and some cultivars of figs—were not adversely affected by these dosages.

Radiation at low doses of 150 to 350 gray (Gy) is effective for ridding papayas, mangos, bananas, pineapples, and grapefruits of insect infestations (*127*). A dose of 250 Gy has an adverse effect on only grapefruits: it increases skin pitting, scald, and decay. Radiation can inhibit ripening of papayas, mangos, and bananas and can therefore prolong their retention of firmness and shelf life (*649*).

Low doses of 80 to 100 Gy will inhibit sprouting of potatoes and onions. The low doses may increase the susceptibility of potatoes to decay, internal black spot, and after-cooking darkening and may cause discoloration of the internal growing points of onions (*185, 810*).

Commercial application of gamma radiation is limited due to the cost and size of equipment needed for the treatment and to uncertainty about the acceptability of irradiated foods to the consumer. Nevertheless, gamma radiation is an alternative treatment for disinfestation of papayas, mangos, and grapefruits.

Ultraviolet lamps are sometimes used to control bacteria and mold in refrigerated storages. Although ultraviolet light has a lethal effect on bacteria and fungi that are sufficiently exposed to the direct rays, there is no evidence that it reduces decay of packaged fruits and vegetables in storage. In tests with several fruits, treatment with ultraviolet light as the fruits passed over a grader did not control decay (*204*).

Protective Packaging

Product protection to maintain quality for an adequate marketing period is the major function of produce packaging. Packages and containers must facilitate product handling during both storage and distribution while protecting the commodity from all sources of deterioration. Today, packages must be amenable to unitized handling, such as palletizing or loading onto slip sheets. Therefore, good stacking strength and rigidity are important assets of desirable containers. Both storage and shipping containers must protect products from physical damage, such as impact bruises, compression bruises, and abrasion bruises. Impact bruises come from dropping containers; container construction and padding can influence the incidence of impact bruising. Compression bruises come from improper or inadequate packaging, especially when overfilled containers are stacked. Abrasion bruises may result when products are not immobilized within containers. Excelsior, plastic foam, or macerated paper pads are recommended for tight-fill fruit containers for bruise protection.

Most horticultural packages must perform under high relative humidity, that is, 90 to 95 percent or even higher. Water vapor released by the products may create near 100 percent relative humidity within the container. Under such conditions, the container must still be capable of withstanding handling abuses. Some containers must tolerate contact with water—sometimes for prolonged periods, as when package or top ice is used or the containers are hydrocooled. Fiberboard containers need special treatments to withstand water; and the treatments, which may be waxing or resin impregnation, add to the expense. During distribution and, to a lesser extent, during storage, product wilting, shriveling, and drying can result from water loss. Desiccation can be minimized through the use of moisture-retentive plastic packaging materials. Film box liners, bags, curtains, pallet covers, and film tarpaulins are used to reduce moisture loss from fruits, vegetables, and nursery stock (*629, 789, 790*).

The most common container for prolonged storage is the wooden pallet bin or bulk box of large capacity. It is used for apples, pears, peaches, plums, citrus, and many other products. It is sturdy and gives good protection, but careful handling during filling and dumping is important. The depth of filling affects the amount of damage.

Nailed wooden boxes and wire-bound veneer crates have good to excellent stacking strength, and both stand up well under high humidity and wet conditions. The open-type construction of wire-bound crates allows good ventilation for rapid cooling in forced-air precoolers and good drainage if hydrocooled.

Fiberboard boxes are now the most popular shipping containers, and they come in many sizes and types—from single-layer fruit packs to master containers with dividers holding a dozen 2.3-kg (5-lb) consumer bags. Boxes with a full-telescope cover have increased strength. Fiberboard boxes and nailed wooden boxes may be used with an assortment of molded trays of foam plastic, paper pulp, or plastic for each layer of apples, peaches, and so forth. Each fruit is in a separate depression in the tray for bruise and abrasion protection.

Burlap and mesh bags provide a handling unit but little protection. Large polyethylene or polypropylene bags have the added value of preventing moisture loss. They must be perforated to preclude undesirable modification of the internal atmosphere.

Efforts to standardize container types have been underway for some time and are needed to reduce the very large number of types and sizes in use (*924*). A few standard con-

tainer sizes that are best suited to the international metric pallet (120 cm by 100 cm) likely will eventually be selected. The containers should not hang over the pallet edges.

Consumer packaging of produce generally should be done shortly before marketing to ensure a fresh pack. Many different plastic films, trays, and cartons are used, and they provide different amounts of product protection. Usually if produce is bagged or overwrapped with plastic film in production areas, the packages should be perforated to allow some gas exchange. Even though perforated, the film can retard moisture loss. Polyethylene consumer bags containing products such as apples, citrus, onions, potatoes, and sweetpotatoes need many ventilation holes to prevent the humidity from becoming excessively high inside. Very high humidity can promote decay, surface mold, and root growth at temperatures usually encountered at the wholesale or retail level or in the home (*334, 336*). Shrink-films are used to package produce tightly so that it is immobilized and less susceptible to damage from chafing during normal handling.

Chilling Injury

Certain fruits, vegetables, and ornamentals are injured by low but nonfreezing temperatures. Crops of tropical origin are generally subject to this physiological injury when exposed to temperatures below 10° to 13°C but above their freezing points (*175, 556, 642*). Certain horticultural crops of temperate zone origin are also susceptible to chilling injury. Those temperate crops, in general, have lower critical temperatures (below 5° to 10°) (*106*). At these temperatures, the tissues weaken because they are unable to carry on normal metabolic processes. Various physiological and biochemical alterations occur in chilling-sensitive species in response to chilling stress (*996*). These alterations lead to the development of a variety of chilling injury symptoms. Often products that are chilled look sound when removed from low temperatures. However, symptoms of chilling, such as pitting or other skin blemishes, internal discoloration, or failure to ripen, become evident in a few days at warmer temperatures. Fruits and vegetables that have been chilled may be particularly susceptible to decay. Alternaria rot is often severe on tomatoes (*608*), squash (*603*), peppers (*604*), and melons that have been chilled. Both time and temperature are involved in chilling injury. Damage may occur in a short time if temperatures are considerably below the danger level, but a product may be able to withstand temperatures a few degrees in the danger zone for a longer time. The effects of chilling are cumulative in some commodities. Low temperatures in transit, or even in the field shortly before harvest, add to the total effects of chilling that might occur in storage. Chilling injury, if a factor in storage, is discussed under each commodity. Many of the commodities susceptible to chilling injury are listed in table 6, together with some of the symptoms.

Treatments which have been shown to alleviate chilling injury include intermittent warming, temperature preconditioning, controlled atmosphere storage, pretreatments with calcium or ethylene, hypobaric storage, waxing, film packaging, chemical applications, and genetic manipulation. Avoiding exposure to chilling temperatures and using other means for storage, such as a controlled atmosphere or treatment with senescence inhibitors, are the alternative for maintaining quality of the chilling-sensitive crops. (See also *601, 707, 996.*)

Freezing Injury

The temperatures usually recommended for storing fresh commodities that are not susceptible to chilling injury are slightly above the freezing point, as shown in tables 7, 13, and 15. The highest temperatures at which freezing (temperatures at which ice crystals form in the tissues of the various commodi-

Table 6
Fruits and vegetables susceptible to chilling injury when stored at moderately low but nonfreezing temperatures

Commodity	Approximate lowest safe temperature °C	Approximate lowest safe temperature °F	Character of injury when stored between 0°C and safe temperature[1]
Apples–certain cultivars	[2]2–3	36–38	Internal browning, brown core, soggy breakdown, soft scald
Asparagus	0–2	32–36	Dull, gray-green, and limp tips
Avocados	[2]4.5–13	40–55	Grayish-brown discoloration of flesh
Bananas, green or ripe	[2]11.5–13	53–56	Dull color when ripened
Beans (lima)	1–4.5	34–40	Rusty brown specks, spots, or areas
Beans (snap)	[2]7	45	Pitting and russeting
Cranberries	2	36	Rubbery texture, red flesh
Cucumbers	7	45	Pitting, water-soaked spots, decay
Eggplants	7	45	Surface scald, alternaria rot, blackening of seeds
Guavas	[2]4.5	40	Pulp injury, decay
Grapefruit	[2]10	50	Scald, pitting, watery breakdown
Jicama	13–18	55–65	Surface decay, discoloration

Table 6
Fruits and vegetables susceptible to chilling injury when stored at moderately low but nonfreezing temperatures —Continued

Commodity	Approximate lowest safe temperature °C	°F	Character of injury when stored between 0°C and safe temperature[1]
Lemons	[2]11-13	52-55	Pitting, membranous staining, red blotch
Limes	7-9	45-48	Pitting, turning tan with time
Mangos	[2]10-13	50-55	Grayish scaldlike discoloration of skin, uneven ripening
Melons			
Cantaloups	[2]2-5	36-41	Pitting, surface decay
Honey Dew	7-10	45-50	Reddish-tan discoloration, pitting, surface decay, failure to ripen
Casaba	7-10	45-50	Same as above but no discoloration
Crenshaw and Persian	7-10	45-50	Same as above but no discoloration
Watermelons	4.5	40	Pitting, objectionable flavor
Okra	7	45	Discoloration, water-soaked areas, pitting, decay
Olives, fresh	7	45	Internal browning
Oranges, California and Arizona	[2]3	38	Pitting, brown stain
Papayas	7	45	Pitting, failure to ripen, off-flavor, decay
Peppers, sweet	7	45	Sheet pitting, alternaria rot on pods and calyxes, darkening of seed
Pineapples	[2]7-10	45-50	Dull green when ripened
Pomegranates	4.5	40	Pitting, external and internal browning
Potatoes	3	38	Mahogany browning (Chippewa and Sebago), sweetening[2]
Pumpkins and hardshell squashes	10	50	Decay, especially alternaria rot
Sweetpotatoes	13	55	Decay, pitting, internal discoloration; hardcore when cooked
Tamarillos	3-4	37-40	Surface pitting, discoloration
Tomatoes			
Ripe	[2]7-10	45-50	Watersoaking and softening, decay
Mature-green	13	55	Poor color when ripe, alternaria rot

[1] Symptoms often apparent only after removal to warm temperatures, as in marketing.
[2] See text.

ties) may occur are given. Cultivars and growing conditions may affect the freezing point. Therefore, an average temperature usually is used in stating a freezing injury for a given commodity. But the highest freezing point is a better guide toward the prevention of freezing. For a discussion of freezing points and the factors affecting them, see *693, 694, 1030*.

Tissues injured by freezing generally lose rigidity, become mushy upon thawing, and appear water soaked. Complete descriptions of freezing injury are found in U.S. Department of Agriculture publications on market diseases (*367, 368, 606, 718, 748, 749, 851, 869, 889*).

Commodities vary widely in their susceptibility to freezing injury. Some may be frozen and thawed a number of times with little or no injury, whereas others are permanently injured by even slight freezing. The freezing point of the commodity is no indication of the damage to be expected by freezing. For example, tomatoes and parsnips both have freezing points of −1.1° to −0.6°C, but parsnips can be frozen and thawed several times without apparent injury, whereas tomatoes are ruined after one freezing. As with chilling injury, severity of freezing injury is influenced by a combination of time and temperature. Apples that would be injured little by exposure for a few days at temperatures slightly below the freezing point would be severely injured by just a few hours' exposure to −7° to −10°.

Susceptibility to freezing injury is not necessarily similar for the same type of vegetable or fruit. For example, leafy lettuce is very susceptible to freezing injury, whereas some other leafy vegetables, such as kale and cabbage, can withstand several light freezings without serious injury.

The tabulation shown gives the relative susceptibility of a number of commodities to actual freezing injury. The commodities are arranged somewhat arbitrarily into three groups: (1) most susceptible, those that are likely to be injured by even one light freezing; (2) moderately

susceptible, those that will recover from one or two light freezings; (3) least susceptible, those that can be lightly frozen several times without serious damage. Even though a number of commodities are somewhat tolerant to freezing, it is desirable to avoid subjecting them to freezing temperatures. Often the storage life is shortened by freezing. Apples that recover from freezing are softer than normal fruit; hence, they should be marketed quickly. Carrots that have been frozen are especially subject to decay.

Most fresh fruits and vegetables, when left undisturbed, can usually be cooled one to several degrees below their freezing point before they actually freeze. This cooling without freezing is known as **undercooling** or **supercooling.** They may remain undercooled for several hours, but they will usually start to freeze immediately if jarred or moved.

Fresh commodities at temperatures below their freezing point should not be handled. If permitted to warm above the freezing point, many specimens that were undercooled may escape having ice crystals form in them. Even potatoes, which are very sensitive to freezing damage, have been undercooled for a short time to −3.9°C—about 3° below their freezing point—and then carefully warmed with no freezing symptoms occurring (*413*). Plant tissue is very sensitive to bruising while frozen, and this sensitivity is another reason for leaving commodities undisturbed until they have warmed up. Selecting a suitable thawing temperture involves a compromise. Fast thawing damages tissues, but very slow thawing such as at 0° or 1° permits ice to remain in the tissues too long. Thawing at 4° (40°F) is suggested (*281, 548*).

(See also *105, 601, 780.*)

Ammonia Injury

Escaping ammonia sometimes damages products in storages equipped with direct-expansion refrigeration systems. Slight injury may be indicated by a brown to greenish-black discoloration of the outer tissues of fruits and vegetables. In apples and pears the tissue around the lenticels is discolored. Severe injury may be marked by discoloration and softening of the deeper tissues, and these effects render the products unmarketable.

An ammonia concentration of 0.8 percent caused rather severe injury to apples, pears, bananas, peaches, and onions within an hour (*747*). Grapes were injured by a 1-hour exposure and almonds and filberts by a 1/2-hour exposure to 1 percent ammonia. Concentrations that were barely detectable by odor (0.01 percent) caused the skins of shelled pecans to darken in 15 minutes and those of almond shells in 1 hour (*777*). Peaches are particularly sensitive to ammonia gas; even 0.02 percent for 6 hours caused slight injury (*114*). Daily odor checks for ammonia leaks are a desirable precaution, and installation of an ammonia alarm system may be advisable.

Ammonia fumes are best removed from storage rooms by aeration and washing the contaminated atmosphere with water if this is possible. Apples sometimes recover with only minor injury at the lenticels if the aeration is quick and complete (*878*). Sulfur dioxide serves as a satisfactory neutralizing agent for light ammonia damage to commodities that are tolerant of sulfur dioxide, such as grapes, almonds, and filberts (*198*). The concentration of sulfur dioxide should be less than 1 percent for grapes and less than 5 percent for almonds and filberts. This treatment is unsatisfactory for pecans, sweet cherries, nectarines, Santa Rosa plums, peaches, pears, and walnuts.

As far as is known, refrigerant R-12 is not injurious to fresh fruits and vegetables.

(See also *746*.)

Susceptibility of fresh fruits and vegetables to freezing injury

Group 1, Most susceptible	Group 2, Moderately susceptible	Group 3, Least susceptible
Apricots	Apples	Beets[1]
Asparagus	Broccoli, sprouting	Brussels sprouts
Avocados	Cabbage, new	Cabbage, mature and savory
Bananas	Carrots[1]	Dates
Beans, snap	Cauliflower	Kale
Berries (except cranberries)	Celery	Kohlrabi
Cucumbers	Cranberries	Parsnips
Eggplant	Grapefruit	Rutabagas
Lemons	Grapes	Salsify
Lettuce	Onions (dry)	Turnips[1]
Limes	Oranges	
Okra	Parsley	
Peaches	Pears	
Peppers, sweet	Peas	
Plums	Radishes[1]	
Potatoes	Spinach	
Squash, summer	Squash, winter	
Sweetpotatoes		
Tomatoes		

[1]Without tops.

Effect of Cold Storage on Subsequent Behavior of Fruits and Vegetables

There is a belief that cold storage predisposes fruits and vegetables to rapid deterioration after removal; but there is no evidence to support this viewpoint, except in regard to over-refrigeration

of cold-sensitive products. At unrefrigerated temperatures most commodities usually age quickly and spoil. At refrigerated temperatures aging and decay are greatly retarded; the net result is longer life. Because some of the potential life is used up in storage, the commodity cannot be expected to keep as long after removal as freshly harvested produce. But if the correct temperature and humidity are used and suitable storage periods are not exceeded, the commodity will have a long enough life after removal to pass through normal marketing channels. Fruits and vegetables that are used immediately after storage (as on board ship or for processing) can often be stored slightly longer than the recommended time. Exceptions are commodities, such as peaches and most cultivars of pears, that need to be ripened after removal from storage. These will fail to ripen properly if stored too long. Extremely perishable fruits and vegetables have a short storage life and must be used soon after they are taken from storage. There is no evidence to indicate that fruits and vegetables suffer from shock when removed from cold storage to room temperature.

When fruits or vegetables are removed from a low temperature to a higher one, or when warm air suddenly enters a room containing refrigerated products, moisture often condenses from the air onto the cool surface of the commodity. This is known as sweating; the higher the relative humidity of the outside air, the more marked it becomes. Sweating occurs because the dewpoint of the air is at or above the temperature of the commodity. The dewpoint specifies the temperature at which the air is saturated with water vapor (100 percent relative humidity). Sweating (condensation) should be prevented or minimized whenever possible, particularly with onions and the more tender fruits, because it may favor decay. This does not mean that products that sweat after removal from a refrigerated room will decay; it does mean that conditions are more favorable for decay than if the surfaces remain dry until consumed. However, as far as is known, experimental evidence does not indicate that sweating is actually harmful. Sweating did not increase decay of papayas when they were transferred to a higher temperature for several hours during storage (*11*).

Sweating can be prevented to some extent by allowing fruits and vegetables to warm gradually. Usually, moving commodities stored at 0°C to rooms with temperatures of only 10° or 13° results in little or no condensation. Under commercial conditions, however, such precautions are rarely practical. If possible, products should be removed from storage when the relative humidity of the outside air is low. Ordinarily, the best procedure in very damp weather is to handle the product carefully and get it to the consumer without undue delay. Circulating warm dry air over the product while it is warming is helpful in drying the surface (*942*). Usually no harm is done if the product remains moist for only a short time. The possibility of sweating when products are removed from cold storage should not deter one from using recommended storage temperatures. The deleterious effects of too high a temperature are much greater than any possible effects of sweating.

At times it is necessary to transport or store different commodities together. In such a mixture, it is very important that the commodities be compatible with respect to their requirements for (1) temperature, (2) relative humidity, (3) atmosphere, (4) protection from odors, and (5) protection from gases such as ethylene, which affects physiological responses. Fruits and vegetables have been categorized into different compatability groups in *533*. Deciduous fruits can generally be stored together if they have the same temperature requirements.

There is a cross-transfer of odors when commodities are stored together, and such a transfer between certain commodities is not desirable. Combinations that should be avoided in storage rooms are apples or pears with celery, cabbage, carrots, potatoes, or onions; celery with onions or carrots; and citrus fruit with any of the strongly scented vegetables. Odors from apples and citrus fruits are readily absorbed by meat, eggs, and dairy products. Pears and apples acquire an unpleasant earthy taste and odor when stored with potatoes. Green peppers will taint pineapples if the two are stored or shipped together. It is recommended that onions, nuts, citrus fruit, and potatoes each be stored separately. (See *104*.)

Many commodities produce ethylene as a natural product; and this gas can have undesirable effects, such as causing abscission of leaves and flower petals, yellowing, russetting, and senescence (*88, 513, 763*). Thus, commodities sensitive to ethylene should not be mixed or stored with those producing the gas (see ethylene section under flowers, p. 86). Commodities that are affected by ethylene include cabbage, carrots, lettuce, various greens, watermelons, kiwifruit, nursery stocks, and some kinds of flowers and florist greens. Commodities that are known to produce considerable ethylene are apples, avocados, bananas, pears, peaches, plums, cantaloups, honey dew melons, and tomatoes (*91, 128, 130, 635, 646*). *Penicillium digitatum* (green mold of citrus) and probably other decay organisms also produce ethylene

(*88, 128, 425*), so decayed produce should be removed promptly from storage rooms.

Ethylene also induces ripening of many fruits and vegetables. This ripening effect generally is negligible at 0°C but may cause harm at higher temperatures. For this reason, products such as cucumbers, peppers, and acorn squash, which need to be stored at a minimum temperature of 7° to 10° and in which retention of green color is desired, should not be stored with apples, pears, tomatoes, or other ethylene-producing crops.

Discussions of ethylene—its production and role in the postharvest physiology of fruits and vegetables—are contained in *6, 91, 130, 646, 733*.

The recommended requirements for storing fresh fruits commercially, along with certain other pertinent information, are given in table 7. Detailed descriptions of the storage requirements are given in the text.

Apples

(Temperature, −1° to 4°C (30° to 40°F), see text; relative humidity, 90 to 95 percent)

More apples are stored on a tonnage basis than any other fruit, and the average storage period is longer. In 1983, the commercial crop in the United States was 3.68 million tonnes (4.05 million tons).

Early, or summer-maturing, apples are seldom stored except temporarily, as most of them are perishable and go directly to market. Refrigeration is highly desirable for even short-term holding. Apples respire and soften about twice as fast at 4°C as at 0°; and at 15°, about three times as fast as at 4° (*697*).

Some smaller growers use **common storage** or air-cooled storage for short holding. For this, they use an insulated building that they keep cool during the fall months by introducing air during cool nights and keeping the storage closed during warm days. The weakness is that night temperatures are usually not as cold as the desired fruit storage temperatures. Also, introducing dry outside air lowers the relative humidity in the storage room. Almost all commercially stored apples are held in **mechanically refrigerated storages,** some of huge capacity. References *71, 697* deal with the design and operation of refrigerated storage rooms.

The storage life of apples varies widely. Cultivar (table 8), production area, cultural practices, seasonal climatic conditions, maturity when picked, and handling and storage practices affect the storage life. Maturity is particularly important. For maximum storage life, apples must be harvested when mature but not fully ripe. Immature apples have poor eating quality and are likely to shrivel in storage. They are also more susceptible to storage disorders such as scald (*874, 967*) and bitter pit (*718*).

Apples picked too mature, on the other hand, will develop breakdown prematurely and have a short storage life. Water core may increase in apples that remain on the tree after reaching optimum maturity. Slight water core may disappear in cold storage, but moderate to severe water core usually will not. The disorder shortens the storage life of the fruit and eventually results in breakdown (*99, 718*). If water core is moderate to severe in any lot of fruit, it should be marketed early.

The use of preharvest sprays of growth regulators, such as daminozide or naphthalene acetic acid (NAA), to control dropping makes it possible to delay harvesting so that size and color will be enhanced. If, however, the delay in harvesting afforded by sprays extends beyond optimum maturity, the storage potential of the apples will be markedly reduced. Daminozide usually increases the storage life of apples slightly if they are harvested at proper maturity.

Apples that for any reason are likely to have a poor storage potential should be segregated and marketed early (*94, 880, 1061*). Good storage can be wasted on apples poorly chosen for late storage or poorly handled before or after storage. Some system should be used to identify the most mature lots going into storage, as they have the shortest storage life. Small- to medium-size apples keep longest.

The recommended storage temperature for each cultivar is that which is the most effective in retarding ripening and growth of decay-producing organisms and which, nevertheless, avoids low-temperature disorders and the possibility of freezing the apples. For most apple cultivars, the optimum storage temperature is −1° to 0°C with 90 to 95 percent relative humidity. The highest freezing point for apples is about −1.5° (29.3°F); hence, apples can be stored at temperatures of −1° or above. Use of −1° calls for well-controlled temperatures in the storage if freezing of the apples is to be avoided. For a

Table 7
Recommended temperature and relative humidity, approximate storage life, highest freezing point, water content, and specific heat of fresh fruits in commercial storage[1]

Commodity	Temperature °C	Temperature °F	Relative humidity (percent)	Approximate storage life	Highest freezing point[1] °C	Highest freezing point[1] °F	Water content (percent)	Specific heat[3] (Btu/lb · °F)
Apples	−1-4	30-40	90-95	1-12 months	−1.5	29.3	84.1	0.87
Apricots	−0.5-0	31-32	90-95	1-3 weeks	−1.0	30.1	85.4	.88
Avocados	[4]4.4-13	40-55	85-90	2-8 weeks	−.3	31.5	76.0	.81
Bananas, green	13-14	56-58	90-95	([5])	−.7	30.6	75.7	.81
Berries								
Blackberries	−0.5-0	31-32	90-95	2-3 days	−.7	30.5	84.8	.88
Blueberries	−0.5-0	31-32	90-95	2 weeks	−1.2	29.7	83.2	.86
Cranberries	2-4	36-40	90-95	2-4 months	−.8	30.4	87.4	.90
Currants	−0.5-0	31-32	90-95	1-4 weeks	−1.0	30.2	84.7	.88
Dewberries	−0.5-0	31-32	90-95	2-3 days	−1.2	29.7	84.5	.88
Elderberries	−0.5-0	31-32	90-95	1-2 weeks	—	—	79.8	.84
Gooseberries	−0.5-0	31-32	90-95	3-4 weeks	−1.0	30.0	88.9	.91
Loganberries	−0.5-0	31-32	90-95	2-3 days	−1.2	29.7	83.0	.86
Raspberries	−0.5-0	31-32	90-95	2-3 days	−1.0	30.0	82.5	.86
Strawberries	0	32	90-95	5-7 days	−.7	30.6	89.9	.92
Carambola	9-10	48-50	85-90	3-4 weeks	—	—	90.4	.92
Cherries, sour	0	32	90-95	3-7 days	−1.7	29.0	83.7	.87
Cherries, sweet	−1 to −0.5	30-31	90-95	2-3 weeks	−1.8	28.8	80.4	.84
Coconuts	0-1.5	32-35	80-85	1-2 months	−.9	30.4	46.9	.58
Dates	[4]−18 or 0	0 or 32	75	6-12 months[4]	−15.7	3.7	22.5	.38
Figs, fresh	−0.5-0	31-32	85-90	7-10 days	−2.4	27.6	78.0	.82
Grapefruit, Calif. & Ariz.	14-15.5	58-60	85-90	6-8 weeks	—	—	87.5	.90
Grapefruit, Fla. & Texas	10-15	50-60	85-90	6-8 weeks	−1.0	30.0	89.1	.91
Grapes, Vinifera	−1 to −0.5	30-31	90-95	1-6 months[4]	−2.1	28.1	81.6	.85
Grapes, American	−0.5-0	31-32	85	2-8 weeks	−1.2	29.7	81.9	.86
Guavas	5-10	41-50	90	2-3 weeks	—	—	83.0	.86
Kiwifruit	−0.5-0	31-32	90-95	3-5 months	−1.6	29.0	82.0	.86
Lemons	([5])		85-90	1-6 months[5]	−1.4	29.4	87.4	.90
Limes	9-10	48-50	85-90	6-8 weeks	−1.6	29.1	89.3	.91
Loquats	0	32	90	3 weeks	—	—	86.5	.89
Lychees	1.5	35	90-95	3-5 weeks	—	—	81.9	.86
Mangos	[5]13	55	85-90	2-3 weeks	−.9	30.3	81.7	.85
Nectarines	−0.5-0	31-32	90-95	2-4 weeks	−.9	30.4	81.8	.85
Olives, fresh	[4]5-10	41-50	85-90	4-6 weeks[4]	−1.4	29.4	80.0	.84
Oranges, Calif. & Ariz.	3-9	38-48	85-90	3-8 weeks	−1.2	29.7	85.5	.88
Oranges, Fla. & Texas	0-1	32-34	85-90	8-12 weeks	−.7	30.6	86.4	.89
Papayas	7	45	85-90	1-3 weeks	−.9	30.4	88.7	.91
Passion fruit	7-10	45-50	85-90	3-5 weeks	—	—	75.1	.80
Peaches	−0.5-0	31-32	90-95	2-4 weeks	−.9	30.3	89.1	.91
Pears	−1.5 to −0.5	29-31	90-95	2-7 months[4]	−1.5	29.2	83.2	.87
Persimmons, Japanese	−1	30	90	3-4 months	−2.1	28.1	78.2	.83
Pineapples	[5]7-13	45-55	85-90	2-4 weeks[4]	−1.1	30.0	85.3	.88
Plums and prunes	−0.5-0	31-32	90-95	2-5 weeks[4]	−.8	30.5	86.6	.89
Pomegranates	5	41	90-95	2-3 months	−3.0	26.6	82.3	.86
Quinces[1]	−0.5-0	31-32	90	2-3 months	−2.0	28.4	83.8	.87
Tangerines, mandarins, & related citrus fruits	4	40	90-95	2-4 weeks	−1.0	30.1	87.3	.90

1 Recommended storage temperatures; temperatures for ripening certain fruits given in text.
2 Data from Whiteman (*1030*).
3 Specific heat calculated from Siebel's (*838*) formula: S = 0.008 × (percent water in food) + 0.20. In metric units of kJ/kg/°C, S = 0.0335 × (percent water in food) + 0.8374.
4 See text for maturity and cultivar differences.
5 See text.

Table 8
Normal and maximum storage periods for certain apple cultivars and their susceptibility to storage disorders

Cultivar	Months of storage		Storage scald susceptibility	Other disorders likely to occur in storage[2]
	Normal	Maximum[1]		
Baldwin	4-5	6-7	Moderate	Bitter pit, brown core
Cortland	3-4	6-7	Very high	Senescent breakdown
Delicious	5-6	8-11	Moderate	Bitter pit, senescent breakdown, soft scald
Empire	4-5	8-9	Slight	—
Golden Delicious	5-6	7-11	Slight	Shriveling, bitter pit, senescent, breakdown
Gravenstein	2	3	Moderate	Bitter pit, Jonathan spot
Granny Smith	5-6	7-9	High	Bitter pit, brown core, senescent breakdown
Idared	5-6	8-9	Slight	Breakdown, Jonathan spot
Jonathan	3-4	6-8	Moderate	Breakdown, Jonathan spot, soft scald
McIntosh	4-5	7-8	Moderate	McIntosh breakdown, brown core
Northern Spy	4-5	7-8	Slight	Senescent breakdown, Spy spot, bitter pit
Rome Beauty	5-6	7-8	Very high	Jonathan spot, soft scald
Spartan	5-6	7-10	Slight	Spartan breakdown, brown core
Stayman Winesap	4-5	7-8	Very high	Senescent breakdown
Winesap	5-6	8-9	High	Senescent breakdown
Yellow Newtown	5-6	8-9	High	Internal browning, senescent breakdown, bitter pit
York Imperial	4-5	6-7	Very high	Cork spot

1 For maximum storage, cultivars must be harvested at optimum maturity, stored under ideal temperature and humidity, and in most cases in the recommended controlled atmosphere. Some fruit may be stored 1-2 months longer than shown.

2 Water core not listed for Delicious, Jonathan, Winesap, Stayman, and others, as it is present at harvest and does not develop in storage.

cultivar such as Delicious, storage at −1° will give approximately 25 percent longer storage life than will storage at 0°. Storage life is reduced as storage temperature is increased.

In New york, the usual recommended temperature for storing mixed cultivars in the same room is 0°C rather than −1° to minimize the possibility of low-temperature disorders (*99*).

Fruit temperatures within stacks of fruit are often several degrees higher than the air temperature as shown by an aisle thermometer. In the Pacific Northwest it is recommended that the warmest fruit after cooling should not be above 0.5°C and the coldest not below −0.5° (fruit temperature). The use of thermocouples placed in the air and in fruit at scattered locations in the storage is desirable. With this equipment accurate fruit temperatures can be determined at any time throughout the room and the risk of relying on air-temperature readings from a single thermometer is removed. If cold spots exist, rearranging stacking patterns and redirecting the air in these areas can speed air movement and prevent excessive cooling. The relation of temperature and heat evolution for several apple cultivars is given in table 9.

Somewhat higher storage temperatures than −1° to 0°C are recommended for some cultivars because of their susceptibility to disorders induced by low temperature. In certain seasons and certain areas, these low-temperature disorders may be more serious than in others. Jonathan apples from some areas often develop soft scald in regular cold storage at 0°; therefore, they should be stored at 2°. McIntosh apples often develop brown core during extended storage at 0°; hence, they should be stored at 2° to 3°. Yellow Newtown apples grown in California often develop internal browning when stored at 0°; they should be stored at 3° to 4°. Grimes

Table 9
Rates of heat evolution (Btu/ton/24 h) by 10 apple cultivars at different temperatures[1]

	Temperature				
Cultivar	−1°C (30°F)	0°C (32°F)	2.2°C (36°F)	3.3°C (38°F)	4.4°C (40°F)
Delicious	690	760	910	1,010	1,110
Golden Delicious	730	800	970	1,070	1,180
Jonathan	800	880	1,060	1,170	1,290
McIntosh	730	800	970	1,070	1,180
Northern Spy	820	900	1,090	1,200	1,320
Rome Beauty	530	580	700	780	850
Stayman Winesap	820	910	1,100	1,210	1,330
Winesap	530	590	710	780	860
Yellow Newton	510	570	690	760	840
York Imperial	610	670	810	900	990
Mean	680	750	900	1,000	1,100

[1] Adapted from Tolle (*951*). To convert Btu/ton/24 h to metric units of kJ/ton/24 h. multiply bv 1.055.

Golden apples are usually stored at −1° to 0°, but those grown in some areas should be stored at 1° to 2° to avoid soggy breakdown.

Unfortunately, fruit ripening is much faster at the warmer temperatures and storage life is reduced. Decay and other disorders, such as Jonathan spot and bitter pit, may be worse at storage temperatures higher than −1° to 0°C. Controlled-atmosphere storage is the main commercial method of compensating for the higher storage temperature required for McIntosh and Yellow Newtown. Storage of Jonathan apples in controlled-atmosphere rooms at 0° provides good control of soft scald and Jonathan spot (*202*).

Controlled-atmosphere (CA) storage involves refrigerating an insulated gastight room and controlling the atmosphere within so that it is higher in carbon dioxide and lower in oxygen than normal. In early constructed CA rooms fruit respiration consumed the oxygen until it reached the desired level; thereafter, the concentration of oxygen was controlled by permitting outside air to enter the room. Now most CA rooms have atmospheric generators that burn the oxygen from the air much more rapidly than can be done by fruit respiration. Excess carbon dioxide from fruit respiration in the gastight rooms must be scrubbed from the air. Scrubbing of carbon dioxide is done with dry lime (*226*), water (*887*), caustic soda, activated carbon, or molecular sieve chemicals (*790, 877*). Use of dry-lime scrubbers is particularly popular because of simplicity, efficiency, and economy. Sacks of dry-hydrated lime are placed directly in the room or adjacent to the CA room, and the air is circulated through the sacks of lime.

Apples in CA storage respire, ripen, and soften more slowly and have fewer disorders than those in air storage. Consequently, CA fruit have a longer storage life and shelf life after removal from storage than fruit stored in air. The storage life of McIntosh in CA may be double that of McIntosh in regular cold storage. CA storage capacity in the United States increased tenfold between 1960 and 1980 (*790*). The pioneering research on CA by Kidd and West (*466, 467, 1027*) and Fidler et al. (*244*) in England, Allen and McKinnon (*25*) and Smock and VanDoren (*885*) in the United States, and others (*200, 760, 879*) contributed to the expansion.

In CA rooms for apples an atmosphere of 1.5 to 3 percent oxygen, 1 to 8 percent carbon dioxide, and the rest nitrogen is carefully maintained. Recommendations for oxygen, carbon dioxide, and CA storage temperatures are given for different cultivars of apples in table 10. A high relative humidity of 90 to 95 percent is recommended in CA rooms. Humidities of 95 percent or as high as possible are best for cultivars that are prone to shrivel, such as Golden Delicious, if the air distribution system is sufficient to prevent local condensation of water. Polyethylene box liners or slipcovers placed over bulk boxes after cooling can help prevent shrivel during prolonged storage (*269, 338*). Storage room floors may be flooded with water to raise the humidity. Also, pallet bins and other wood containers should be moistened before they are placed in storage. This will prevent absorption of moisture from the apples by dry boxes (*714*). Sufficient cooling surface is the best permanent solution for maintaining the high relative humidity desired in the storage.

Although CA storage strikingly benefits McIntosh, Jonathan, and Yellow Newtown cultivars, which develop low-temperature disorders in regular cold storage, it also benefits most other cultivars. Large quantities of the popular Delicious and Golden Delicious cultivars are now stored in CA at −0.5° to 0°C. For McIntosh apples, an atmosphere of 2 to 3 percent carbon dioxide is used during the first month of CA, after which the carbon dioxide level can be raised to 5 percent (*99*). Jonathan apples are stored at 2 to 5 percent carbon dioxide and 2 to 3 percent oxygen at 2.2°C for 1 month, then at 0° for the remainder of storage.

Recent research has shown even better quality retention with a low oxygen level of 1 percent rather than 2 to 3 percent for McIntosh, Golden Delicious, and Delicious cultivars (*36, 510, 760*). However, until further research is done, low-oxygen in this range is too risky for commercial recommendation. In Australia, exposure of Granny Smith apples to an initial stress at 0.5 percent oxygen for 9 days before storage at 1.5 percent oxygen and 1 percent carbon dioxide gave additional benefits of fruit firmness and scald control over regular CA (*537*).

Table 10
Requirements for controlled atmosphere storage of apples[1]

Cultivar	Carbon dioxide (percent)	Oxygen (percent)	Temperature °C	Temperature °F
Cortland	5	2-3	2.2	36
	2-3	2-3	0	32
Delicious	1-2	[2]1.5-2	−0.5-0	31-32
Empire	2-3	2-3	−0.5-0	31-32
Golden Delicious	1-3	[2]1.5-2	−0.5-0	31-32
Granny Smith	1-3	2-3	−0.5-0	31-32
Idared	2-3	2-3	−0.5-0	31-32
Jonathan	0.5-5	2.5-3	2.2 one month then 0	36 one month, then 32
Macoun	5	2-3	2.2	36
McIntosh	2-3 one month, then 5	2.5-3	2.2	36
	2-3 one month, then 5	2	3.3	38
Northern Spy	2-3	2-3	−0.5-0	31-32
Rome Beauty	1-3	2-3	−0.5-0	31-32
Spartan	2-3	2-3	−0.5-0	31-32
Stayman Winesap	2-5	2-3	−0.5-0	31-32
Winesap	1-2	2-3	−0.5	31
Yellow Newtown (Calif.)	8	3	4.4	40
(Oreg.)	5-6	3	2.2	36

[1] Adapted from references *99, 200, 942.*
[2] 1.5 percent oxygen not recommended for Delicious or Golden Delicious in New York, because less than 2 percent oxygen is injurious.

A new, rapid CA procedure is desirable to obtain the best long-term storage results for Golden Delicious, McIntosh, Spartan, and no doubt some other cultivars (*498, 499, 760*). Rapid CA involves a short 2- to 3-day room-loading time plus only a short 1- to 4-day period to establish 2 to 3 percent oxygen by nitrogen flushing or use of an atmospheric generator. Carbon dioxide is scrubbed during the oxygen removal process. The older, conventional practice has been to take 8 to 10 days to fill the room and thoroughly cool the fruit, then to seal the room, and allow fruit respiration to lower the oxygen to 2.5 to 3 percent in 15 to 20 days. This slow CA procedure has frequently failed to produce good results with softer cultivars.

An initial high carbon dioxide treatment before CA storage aids the retention of firmness in Golden Delicious apples and permits an extended packing season. The fruit must be dry when treated to avoid carbon dioxide injury. Carbon dioxide levels of 14 to 17 percent are developed and maintained for 4 to 9 days. Then the carbon dioxide is flushed or scrubbed from the room, and a normal CA atmosphere of 2 to 3 percent oxygen and 1 to 3 percent carbon dioxide at −0.6° to 0°C is established (*176, 683, 760*). The rapid CA procedure described appears to be safer than and as effective as the high carbon dioxide treatment for Washington State Golden Delicious (*682*). With British Columbia Golden Delicious apples, carbon dioxide injury from the treatment has been excessive (*497, 618*). Similar high carbon dioxide treatments of McIntosh apples before CA storage caused injury (*107*).

The benefits of ethylene removal from CA rooms with an absorbent are still being clarified. However, it now has been shown that keeping ethylene very low in rooms with early harvested (preclimacteric) McIntosh and Golden Delicious will result in firmer apples after storage (*470, 542, 543, 734, 760*).

State regulations on CA storage require that the storage remain sealed with a low-oxygen atmosphere a minimum of 90 days for most cultivars and 60 days for Michigan Jonathan apples if they are to be sold as CA fruit. Storages opened sooner probably would yield fruit little or no better than those from air storage. During loading and after opening storages, the temperature should be maintained at −0.6° to 0°C.

Numerous precautions should be taken in operating a CA storage. Foremost, never enter a CA room without an air mask, and always have an outside observer also equipped with an air mask (*99, 71*). A 2- to 3-percent oxygen atmosphere is lethal to humans. On opening the door, air the room until the oxygen

concentration reaches 18 percent or higher before entering.

Other aspects of CA storage are discussed in a preceding section (see p. 23). And further information is available in the proceedings of national CA conferences and other publications (*39, 71, 200, 202, 203, 211, 760, 790, 880, 881, 942, 952, 967*). Promising results with hypobaric storage of apples are presented in *210*.

Apple cold storage rooms should be designed to quickly establish and maintain uniform low temperatures. It is essential that apples be cooled as quickly as possible after harvest. Apples are not injured by rapid cooling. A delay of 1 day at 21°C after harvest takes 7 to 10 days off the potential storage life at 0°. A delay of 3 days in the orchard or in a warm packing shed may shorten their storage life as much as 30 days, even if they are then stored at −1°. Adequate refrigeration capacity to handle the maximum heat load is essential (*819*). If adequate refrigeration and air circulation are not provided, apples may take several weeks to cool and their storage life is shortened. A desirable goal is for core temperatures of fruit in the centers of the stacks to drop to 0° to 0.6° in 2 to 3 days (*99*). Rapid cooling is also important to reduce water loss from transpiration. Apples stored in pallet boxes cool as well as or better than those stored in standard boxes on pallets (*698*).

For good keeping quality, apples must be not only sound and at the right stage of maturity but also carefully handled in all operations, including picking, grading, and packaging (*264, 967*). Bruising damage increases the susceptibility to blue mold decay (*1072*). Slight cuts and stem punctures also serve as points of entry for spores of decay organisms. The main cause of rotten fruits in storage is rough handling. Badly bruised apples actually ripen faster (*99*).

Fruit condition should be checked before storage and periodically during storage by removing samples and examining them for storage disorders and firmness. Standardized procedures for measuring apple firmness are available (*96*). The Effegi and Magness-Taylor firmness testers with a 10.5-mm plunger are in widest use (*3, 320*). Measurements of fruit firmness are a big help in determining the potential storage life of apples. Apples testing 71 newtons (16-lb force) firmness or harder should have a long storage life under good cold-storage conditions. Apples testing 53 newtons (12-lb force) will have little storage life remaining and should be sold early. There are cultivar differences in firmness that must be considered (*3, 94, 320, 697*). Apples must be sold while still firm and in good condition and with sufficient shelf life to permit normal marketing. Good refrigeration throughout marketing channels will ensure that consumers receive crisp, not mealy, apples (*341, 595*).

Storage scald was the most serious disorder of apples both during and after storage. Now, storage operators have a choice of two scald inhibitors, diphenylamine (DPA) and ethoxyquin, that can effectively control this physiological disease. The choice of inhibitor depends on the cultivar to be treated. State agricultural experiment station authorities should be consulted for recommended concentrations (*99, 199*). Many cultivars require treatment. The most economical method of application is drenching or flooding the fruit in bins as it is received from the orchard and prior to placement in storage. Delays in treatment will diminish the effectiveness of scald inhibitors. They can be helpful even if treatment is delayed for up to 2 weeks after harvest but will be of little value if application is delayed a month. Generally, immature or early picked apples are more susceptible to scald. However, late-picked McIntosh and Golden Delicious may develop a "senescent" scald, especially in CA storage. With the exception of early picked Starkrimson Delicious, which is very susceptible to storage scald, DPA or ethoxyquin can be expected to control scald effectively if kept at the desired concentration in the tank.

Scald development is usually less on fruit in CA storage than in regular storage. However, scald-susceptible cultivars should be treated with scald inhibitors before they are placed in CA storage. In years of severe scald development, the inhibitors may not give complete control. Therefore, whether or not the fruit was treated, periodic checks for scald should be made by removing samples and holding them at room temperature for several days. Scald is frequently not visible in storage but develops rapidly when the fruit is moved to warm temperatures. Sample lots showing a scald potential can often be marketed immediately without difficulty. (See *99, 199, 213, 339, 874*.)

Soft scald, a low-temperature disorder, has also been reported to be controlled by the antioxidants DPA and ethoxyquin (*1043*). Since these materials are applied for storage scald control, they might also be used to treat cultivars susceptible to soft scald. Apples permitted to begin ripening before rapid cooling are very susceptible to this disorder. Soft scald is also controlled by avoiding storage at 0°C, avoiding delays in storage, and using CA storage.

The nomenclature for various internal disorders of apples and their symptoms were described in 1977 by Smock (*876*). Several investigators have shown that inducing water loss (weight loss) for a period soon after harvest will reduce senescent breakdown and low-temperature breakdown during subsequent storage of some cultivars (*95, 511, 728, 823*). A more practical solution to delay senescence and control breakdown is to dip or drench fruit with a 3- to 4-percent calcium chloride solution after harvest and before storage. Calcium chloride treatment has also reduced bitter pit, Jonathan spot, and rate of flesh softening as well as given effective control of breakdown. It has been an effective treatment for Jonathan (*62, 206, 825*), Gravenstein (*824*), Spartan (*586*), McIntosh (*95*), and Stayman (*340*). The calcium chloride can be applied in a combined treatment with scald inhibitors or fungicides. Since this chemical is corrosive to metal, equipment must be washed regularly after use.

The main postharvest diseases of apples that develop in storage are discussed in *718, 790*. Blue mold (*Penicillium expansum*) is the most common and usually the most destructive of all the rots. The main points of entry for blue mold spores are mechanical injuries, cuts, and bruises (*1072*). Control of this decay requires careful handling, good packinghouse sanitation, and prompt cooling. Blue mold develops slowly even at 0°C. Commercial control usually involves postharvest applications of fungicides, such as benomyl or thiabendazole (*98, 139, 344*). Sometimes the fungicide is applied with the scald inhibitor. Gray mold rot, caused by *Botrytis*, and alternaria rot, caused by *Alternaria tenius*, are the other leading diseases. Control of both diseases requires careful fruit handling, prompt storage, and maintenance of recommended low temperature. For further information on diseases and disorders of apples see *718, 729*.

For rodent control in storage by fumigation see *99*.

Ethylene-sensitive commodities that should not be stored with apples include carrots, celery, cabbage, lettuce, some kinds of cut flowers, seedlings, nursery stock, and bedding plants. Ethylene is harmful to each of these crops. Apples should not be stored with potatoes, as the fruit will acquire an unpleasant earthy taste.

The literature may be consulted for other information on freezing (*92*), hydrohandling (*207*), operation of CA rooms (*71, 881*), breakdown (*1045*), and storage of prepackaged apples (*1061*).

Apricots

(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Apricots are seldom stored in commercial quantities, although they keep well for 1 to 2 weeks, or possibly even 3 weeks, at −0.5° to 0°C. Fruit picked when firm enough to ship or store have about the same maturity as those commonly used for canning and lack the character and full flavor of tree-ripened fruit. Unfortunately, it is not possible to allow the fruit to reach this desirable stage of maturity for fresh-market use. The greatest hazard in handling or shipping apricots is decay—mainly brown rot and rhizopus rot. Quick cooling of apricots to temperatures of 4° or lower and holding them at as near 0° as possible will retard decay and ripening. Apricots stored at 4° to 7° have less flavor and a more mealy texture after ripening than fruit stored at 0°. Some Japanese cultivars develop a type of chilling injury (pitting or browning of the peel) more rapidly at 5° than at 0° (*435*). Storage at 0° is necessary to minimize this injury. Normal breakdown in apricots appears, much as it does in peaches, as browning around the seed and a softening of the flesh. It is likely to appear after 2 or more weeks at −0.5° to 0°. Ripening temperatures of 18° to 24° are satisfactory for apricots (*847*).

Results of controlled atmosphere (CA) storage tests with Canino apricots were not satisfactory, as more internal browning developed during ripening than in control fruit (*304*). More promising CA results were reported for Blenheim (Royal) apricots held for canning in 2 to 3 percent oxygen and 2.5 to 3 percent carbon dioxide at 0°C. The CA-stored fruit after canning retained flavor better than did air-stored fruit (*160*). In another study, hypobaric or low-pressure storage significantly delayed softening and extended the storage life of apricots (*807*). Evidence is still inadequate to recommend either CA or hypobaric storage for fresh market apricots. (See also *111*.)

Avocados

(Temperature, see text; relative humidity, 85 to 90 percent)

Avocado fruit grow continuously while on the tree, but will ripen only after they are harvested. The older fruit, which generally are larger, will ripen earlier than younger fruit. Ripening and softening can be delayed by precooling the fruit immediately after harvest (*790, 1081*) and placing them in ethylene-free storage at optimum temperature (*222, 375, 1080*). The optimum storage temperature differs with cultivar because cultivars differ in sensitivity to chilling injury. The chilling-tolerant cultivars such as Lula, Booth 1, Booth 8, and Taylor store best at 4.4°C. These chilling-tolerant cultivars can be held 4 to 8 weeks in storage. All West Indian cultivars, which include Fuchs, Pollock, and Waldin, are chilling sensitive and store best at 13° and for a maximum period of 2 weeks. A few cultivars such as Fuerte, Hass, and Booth 7 are intermediate in sensitivity and store best at 7.2°. Hass followed by Fuerte is the leading cultivar grown in California. These cultivars with intermediate chilling sensitivity can be held only about 2 weeks in storage because they ripen slowly even at 7.2°, which can cause chilling injury after an extended time.

Common symptoms of chilling injury are a grayish-brown discoloration of the flesh, scalding and pitting of the skin, and failure of the fruit to soften properly when removed from storage. Chilling-sensitive cultivars may eventually show chilling injury even at 12.5°C; at temperatures below 10° they are highly susceptible to the injury. Chilling-tolerant cultivars are susceptible to injury at temperatures below 4.4° and may eventually sustain injury at 4.4°. At temperatures of 7.2° and higher, anthracnose, or black spot, the most common disease of avocados, may become serious.

Controlled atmospheres decrease chilling sensitivity of avocados, thus allowing storage at a lower temperature and for a longer period. An atmosphere containing 3 to 5 percent oxygen and 3 to 5 percent carbon dioxide delays the softening of Fuerte avocados held at 4.4° or 7°C and reduces the rate at which they ripen when transferred to air at 15°. An atmosphere containing 1 percent oxygen and 9 percent carbon dioxide at 10° maintains Lulu avocados in acceptable eating quality and appearance for 60 days (*375, 790, 898*).

A reduced atmospheric pressure of 60 mm Hg retards ripening of

Hass avocados for 70 days at 6°C, and the fruit will ripen normally at 14° (*50*). Benefits of reduced atmospheric pressure are only slight for Booth 8, Lula, and Waldin fruit held at chilling temperature (*899*).

Research has shown that addition of calcium to avocados reduces the ripening processes and chilling injury. Vacuum infiltration of $CaCl_2$ delayed the ripening of Hass avocados (*950*) and decreased the amount of chilling injury in Hass and Fuerte avocados stored 3 weeks at 5°C (*150*). The magnitude of these responses increased with increasing amounts of calcium infiltrated into the fruit, but the maximum amount added caused a calcium injury.

The best ripening temperatures for avocados are from 15.5° to 24°C, with 15.5° being ideal for best quality (*376*). At 15.5°, however, ripening is comparatively slow. Ripening at temperatures of 25° and higher results in accelerated softening, excessive decay, discoloration, and off-flavors (*90*). Ethylene may be used to stimulate ripening, as for bananas.

(See also *221, 783, 1005, 1006*.)

Bananas

(Pulp temperature: shipping and holding green fruit, 13° to 14°C (56° to 58°F); ripening, 14° to 20° (58° to 68°); holding ripe fruit, 13° to 14° (56° to 58°). Relative humidity: green or turning fruit, 90 to 95 percent; ripe fruit, 85 percent)

Bananas must be green when shipped to market so that they will not soften or sustain much serious injury and bruising during handling. Most bananas are now removed from the stem in the tropics, and hands are shipped in corrugated boxes. Boxing eliminates many sources of handling damage previously encountered in shipping stems. Potential crown rot of hands can be controlled by use of fungicides. Rough handling of ripe or turning fruit may cause darkening of the bruised pulp; but evidence of damage may not be apparent externally (*962*).

The lowest temperature at which green bananas can safely be held to delay ripening is about 13°C pulp temperature; below this they become chilled and injury to the peel results. Green bananas are shipped at a temperature range of 13° to 14° pulp temperature. The Gros Michel cultivar is an exception and often is transported at temperatures as low as 12° for short periods. Both green and ripe bananas are susceptible to chilling injury, but green fruit are slightly more susceptible. Chilling mainly injures the peel, killing certain cells. The dead cells darken and give the peel a characteristic smokey or dull-yellow appearance after ripening rather than a bright-yellow color. Ripe fruit if chilled turn dull brown when later exposed to higher temperatures and are very susceptible to handling marks; the slightest pressure causes discoloration.

The exact upper limits of temperatures causing chilling vary somewhat with the condition of the fruit, the cultivar, and duration of exposure. Generally temperatures below 12°C cause chilling injury. A few hours at 10° may cause slight peel dulling, and 12 hours at 7° generally causes enough chilling injury to affect salability of the fruit (*33, 962*). Although chilled fruit have a poor appearance when ripened, flavor and consistency may differ little from those of normal fruit if chilling damage is not severe.

Banana ripening is accomplished at temperatures ranging from 14° to 20°C pulp temperature, with high relative humidity of 90 to 95 percent. Ripening temperatures between 14° and 18° usually are best when ethylene is used. Within certain limits, the period required for ripening green fruit can be extended or shortened to meet trade requirements by adjusting the temperature (table 11). Under average conditions, the ripening period may be as short as 4 days with higher temperatures or it may be extended to 8 to 10 days with lower temperatures. Ripening-room temperatures for bananas are varied frequently in contrast to those for other produce (*33, 731, 962*). Ripening characteristics of bananas vary with country of origin, cultivar, days in transit, season of the year, maturity when harvested, and other factors. The desired high humidity required for proper ripening is attained when bananas are held in boxes with polyethylene liners. After coloring is well underway, relative humidity should be about 85 percent.

It is recommended that air-circulating fans be operated continuously when ripening boxed fruit so that a uniform pulp temperature is maintained throughout the room.

Stacking to allow adequate air circulation is essential for uniform ripening of boxed bananas. Many stacking patterns are available; the best pattern to use depends upon pallet sizes and processor facilities. Ideally, boxes should be stacked in rows with a 10 cm (4-in) air channel between adjacent rows.

The addition of ethylene gas to ripening rooms always is recommended to stimulate ripening of tropically boxed Valery, Cavendish, and Gros Michel bananas. A concentration of 1,000 p/m, or 1 ft^3 ethylene/1,000 ft^3 of room volume, is commonly used. A low level of only 1 p/m is necessary to stimulate ripening if the oxygen and carbon dioxide levels are similar to those

Table 11
Approximate daily pulp temperatures desired for bananas scheduled to complete ripening in specified number of days[1]

Ripening schedule	Fruit temperature (°C) on day— 1	2	3	4	5	6	7
4 days	18	18	17	16			
5 days	17	17	17	17	16		
6 days	17	17	16	16	16	14	
7 days	16	16	16	16	16	14	14

[1] Adapted from reference *962*.

found in outside air (*540*). After 24 hours of ethylene treatment the rooms should be ventilated. Such a treatment assures uniform coloration on a predetermined schedule and allows use of lower-than-normal ripening temperatures, which will result in increased shelf life (*33*). The recommended temperature of boxed and gassed bananas is 16° to 17°C (*731*).

The best holding temperature for ripe bananas is 13°C for Gros Michel and 14° for Valery. Even at these temperatures ripe fruit cannot ordinarily be held for more than 2 to 4 days. Ripening should be timed so that holding ripe fruit is kept to a minimum. Exposing ripe bananas to temperatures higher than those in the ripening range hastens softening and decay, weakens the neck and peel, and may cause poor color. The term "cooked" is normally used to describe this type of injury in its extreme stage.

Shelf life of green bananas may be extended during storage by continuous removal of ethylene within containers or storage room and/or by use of a controlled atmosphere (*539, 541, 695, 743*). Research has shown that the combined use of both a reduced level of oxygen and an increased level of carbon dioxide delays ripening. The shelf life may be extended 2 to 3 times by using an atmosphere of 4 percent oxygen and 5 percent carbon dioxide (*616*). Carbon dioxide inhibits the effect of ethylene on ripening, so bananas stored in controlled atmosphere should be ventilated with fresh air when ripening is desired.

For further information on handling and ripening bananas consult references *317, 584, 840, 853, 913, 963, 989*.

Berries

Blackberries and Related Berries
(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Blackberries, dewberries, loganberries, boysenberries, and youngberries are not adapted to storage and usually are not stored commercially. If brief holding is necessary, prompt precooling to −0.5° to 0°C is desirable. This temperature should be maintained with a relative humidity of 90 to 95 percent. These berries cannot be stored satisfactorily for more than about 2 to 3 days because longer storage results in loss of good marketing quality. An atmosphere high in carbon dioxide (20 to 40 percent) can be used to maintain the quality of machine-harvested blackberries destined for processing during storage at 20° for up to 48 hours (*639*).

Blueberries
(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Blueberries in good condition can be stored at −0.5° to 0°C with high relative humidity for about 2 weeks. With some loss in quality, storage can be extended to 4 to 6 weeks (*126, 415*). Rapidly precooling fresh blueberries to near 0° and maintaining that temperature suppresses decay development and preserves the market quality (*418*). Mixtures of the soft-ripe berries with hard-ripe berries, as may occur with late pickings, have poor storage potential because overmaturity contributes to deterioration. The ratio of soluble solids to acids increases with increasing ripeness. When the ratio exceeds 30, the fruit should not be sent to fresh markets but should instead be processed within 24 hours (*60*). Also, blueberries with more than a trace of visible decay at harvest have a poor storage potential; hence, they should be marketed promptly rather than be allowed to contribute to storage losses.

Moisture losses can be kept to 2 to 3 percent or less during storage and marketing through use of proper packaging, film caps, and maintenance of 90 to 95 percent relative humidity (*415*). Handling of blueberries should be minimized to avoid damaging the bloom. Blueberries stored at temperatures of 4.5°C and above gradually develop an undesirable tough-textured skin.

Research with controlled atmospheres showed that CA storage retarded breakdown and decay but caused off-flavors (*126*). Use of sealed 1.5-mil polyethlene lug liners increased storage life by reducing weight loss and maintaining turgidity, appearance, and flavor. However, prolonged storage beyond 6 weeks at 0°C in film liners sometimes resulted in off-flavored fruit (*415*).

See *367* for market diseases of blueberries.

Cranberries
(Temperature, 2° to 4°C (36° to 40°F); relative humidity, 90 to 95 percent)

Part of the cranberry crop is stored in field boxes for marketing as fresh fruit during the peak Thanksgiving and Christmas holiday seasons. Common (air-cooled) ventilated storages located near the bogs are often used. However, refrigerated storage at 2° to 4°C with 90 to 95 percent relative humidity provides better conditions and reduces spoilage and moisture losses (*241, 414, 507, 762, 1068*). In addition, cranberries from cold storage have an extended shelf life during marketing. Fresh cranberries are usually not stored longer than 2 months. However, they can be stored for 3 to 4 months at 2° to 4°. Storage for more than 4 months is usually not satisfactory because of shrinkage due to moisture loss, physiological breakdown, end rot, and other fungus diseases that can develop even at low temperature (*367, 587, 1068*). Extended storage at −1° or 0° will cause chilling and physiological breakdown, described below (*507, 1068*).

Poorly colored fruit can be held at 7° to 10°C for a few weeks to permit more rapid coloring than would occur at lower temperatures (*507*).

Keeping quality is determined to some extent by maturity and cultivar. However, storage life of fruit from the same bogs may vary from year to year. Early harvested berries usually have a longer storage potential than late-harvested fruit (*214*).

Most cranberries are still stored unscreened and "in the chaff," just as they come from the field. They keep better this way than if handled additionally to clean, sort, and

remove field debris before storage. A minimum of handling both before and after storage will reduce spoilage. Studies have shown that screening and impact bruising predispose cranberries to physiological breakdown or postharvest softening (*289, 587, 701*).

Cleaned and sorted cranberries can safely be stored in crates or in ventilated consumer units (cartons or film bags) for 2 to 3 weeks at 0°C or 6 weeks at 4° (*414, 762*). Longer storage at 0° may bring on physiological breakdown or chilling injury. Berries in this condition have red-pigmented rubbery-textured flesh rather than the normal crisp, white flesh and have less natural skin luster. Such berries closely resemble those that have been either frozen, smothered, or seriously bruised (*367, 408, 507, 587*). Recent research has shown that warming cranberries stored at 0° to 21° for 1 day each month can help avoid some chilling injury (*408*).

Smothering injury may develop in cranberries stored under poorly ventilated conditions. It is caused by holding berries in tight containers or in overloaded storage spaces where carbon dioxide accumulates and oxygen is depleted. Berries held too long under water may also be smothered. Harvested berries immersed in a flooded bog for 8 to 12 hours or more develop more physiological breakdown in storage (*146*).

Most of the cranberry crop is now processed into sauce or juice. Fruit intended for processing are screened as rapidly as possible and are utilized or frozen shortly after harvest. Such fruit can be frozen at −18°C until needed without quality loss. Freezing berries enhances development of the desired color in the juice. A Wisconsin study (*934*) showed for up to 10 weeks, that refrigerated storage at 4°C is effective in preserving cranberries that are to be processed.

Controlled or modified atmospheres have not been effective in extending the storage life of fresh cranberries beyond that possible with conventional cold storage (*40*). Storage in cartons with sealed polyethylene liners has increased the extent of decay and breakdown at 3°C (*40*).

Further information is available on handling (*241*), precooling (*461*), and market diseases (*367, 762*).

Currants, Gooseberries, and Elderberries
(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Currants, gooseberries, and elderberries are not stored except briefly or when they must be held for processing. A temperature of −0.5° to 0°C is recommended. Red or white currants and elderberries in good condition can be stored 1 to 2 weeks. Black currants are stored a maximum of 4 weeks (*463*). If necessary, gooseberries can be stored 3 to 4 weeks but with some losses from collapsing berries. Gooseberries stored at the recommended temperature for as long as 3 to 4 weeks should be processed immediately after removal from storage (*861*).

As soon as picked, currants, black currants, and gooseberries should be precooled to a temperature lower than 4°C to reduce damage during transport to market (*463*).

Gooseberries have been damaged by exposure to 12 percent carbon dioxide for 4 weeks at 0° but not by 8 percent carbon dioxide. Storage of hard-green gooseberries for longer periods at 0° in perforated polyethylene bags is possible if some carbon dioxide is allowed to accumulate (*464*).

Raspberries
(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Fresh raspberries soften and decay rapidly and are not adapted for commercial storage. For maximum life, field heat should be removed immediately after harvest by forced-air precooling to 1°C, and the precooled fruits placed at −0.5° to 0°. This temperature retards ripening and development of gray mold rot, rhizopus rot, and cladosporium rot (*367*) and allows 2 or 3 days of storage prior to marketing (*859, 1048*). Ripening and development of fungal rots are further retarded if raspberries are precooled and transported in an atmosphere containing 20 to 25 percent carbon dioxide through use of dry ice (*859*).

Strawberries
(Temperature, 0°C (32°F); relative humidity, 90 to 95 percent)

Fresh strawberries are highly perishable and cannot be stored except briefly. For maximum life, perhaps of 5 to 7 days, fruit should be precooled immediately after harvest and placed at 0°C. The temperature of harvested strawberries in the field can get up to 30°, and higher when exposed to sun; and when fruits are allowed to remain at this temperature for 4 hours, marketability drops by at least 40 percent (*634*). Precooling of whole pallets by forced air is recommended because the desired temperature (1°) can be obtained within 1 hour, whereas air cooling takes 9 hours (*790*). After a few days in storage, the fruit loses some of its fresh bright color, tends to shrivel, and deteriorates in flavor. Deterioration is arrested by low temperature; but after removal from storage, it proceeds more rapidly than in freshly picked strawberries (*755*). The major diseases causing storage losses in strawberries are gray mold rot, rhizopus rot, and leather rot. Prompt precooling to temperatures of 5° or below and holding at such temperatures in transit, storage, and during marketing will minimize such losses (*367, 600, 634, 755, 894*).

Refrigeration is sometimes supplemented with carbon dioxide gas from dry ice to modify the atmosphere during transit or storage. In air transport, pallets are covered with curtain coated fiberboard or heat-shrink polyethylene to retain the high level of carbon dioxide (*366*). High levels of carbon dioxide (10 to 30 percent) slow the respiration rate of the fruit and reduce the activity of decay-causing organisms, thus extending storage and market life (*178, 352, 364, 983*). Carbon diox-

ide atmospheres of 30 percent or greater can cause off-flavor (*365*).

Low-oxygen atmospheres of 0.5 to 2 percent will also reduce respiration rate and decay, but the fruit develop off-flavor (*178*). Postharvest chemical and heat treatments can be useful in reducing decay during storage and handling (*638, 870, 944, 1010*). However, surface sheen can be lost when fruit are dipped in water or solutions.

Cherries

(Temperature, −1° to 0°C (30° to 32°F); relative humidity, 90 to 95 percent)

The approximate time limit for successful handling of fresh **sweet cherries** from harvest to arrival at eastern markets is about 14 days if transit temperatures do not exceed 2°C. The use of sealed polyethylene liners in containers will extend the cold-storage period by at least an additional week. Thus, sweet cherries can be stored in polyethylene at −1° to −0.5° for 2 weeks after harvest and still be shipped by freight to eastern markets. If cherries are held longer than the periods indicated, they lose flavor and brightness. Loss of moisture is one of the most critical factors affecting the fresh appearance of both the fruit and stems. Stems dry out and darken if the humidity is too low. Field containers of cherries should be covered with a tarpaulin or some other moisture barrier from the time of harvest until packaged for shipment. Sweet cherries are very perishable and deteriorate rapidly at nonrefrigerated temperatures. Prompt cooling is essential.

Modified atmospheres obtained with the use of polyethylene liners can lengthen the market life of sweet cherries (*273, 274*). However, these liners must be opened when fruit are removed from cold storage to prevent development of off-flavors at higher temperatures. Controlled atmospheres with 20 to 25 percent carbon dioxide (*700, 702*) or 0.5 to 2 percent oxygen (*151*) can help maintain firmness, green stems, and bright fruit color during storage.

Surface pitting is a major problem affecting the fresh market quality of cherries (*236, 991*). While no cause-and-effect relationship has been found, the severity appears to be affected by mechanical injury. Calcium treatment (*512*) or low-pressure storage (*991*) has been shown to reduce the incidence of surface pitting.

Most sweet cherries are now handled by mechanical equipment for separating the clusters and sizing the fruit, so a postharvest fungicide spray can be applied without an additional handling operation (*717*). See *368* for a discussion of storage diseases of cherries.

Sour cherries are generally unsuitable for storage, except for holding a few days at 0°C to extend the processing period. (See also *251, 622*.)

Coconuts

(Temperature, 0° to 1.5°C (32° to 35°F); relative humidity, 80 to 85 percent)

Coconuts are best stored at 0° to 1.5°C and can be held satisfactorily within that range for 1 to 2 months. Coconuts are subject to mold, weight loss, and drying up of nut milk. They can usually be held about 2 weeks at room temperature without serious loss (*573*). Weight loss is substantially reduced by coating with paraffin wax (*650*) or packaging in polyethylene. Paraffin waxing also is very effective in reducing stress cracking during transport (*132*). Coconuts can become moldy if the relative humidity is too high.

Dates

(Temperature, see text; relative humidity, 75 percent or less)

Dates are subject to two general types of deterioration. One is caused by microbiological activity and includes fermentation by yeasts and molding by fungi. The other form of deterioration is physiological and includes darkening and loss of flavor and aroma. Susceptibility to both types of deterioration increases with increasing moisture content.

Natural, or nonhydrated, dates are somewhat more subject to attack by micro-organisms than steam-hydrated ones because of the partial sterilization accompanying steam hydration. Dates with 23 percent or less moisture are comparatively safe from microbiological spoilage; they become increasingly susceptible as the moisture content exceeds this percentage. Low temperatures also retard microbiological deterioration.

Physiological deterioration of dates is influenced by temperature, moisture content, and type of date. Moisture content is particularly important at higher temperatures. At 24°C, Deglet Noor dates with 20 percent moisture retain color four times as long as those with 24 percent moisture (*795*). Similar relationships occur at cold storage temperatures. A high moisture content gives dates the soft texture many consumers prefer but increases perishability; hence, low temperatures are necessary for successful storage. Dates are not subject to low-temperature injury or freezing injury, so temperatures below 0°C are not harmful.

For best retention of flavor, texture, color, and aroma, Deglet Noor and similar cultivars should be stored at 0°C or lower. They can be held for a year at 0°, somewhat longer at −18°, about 8 months at 5°, 3 months at 15°, and 1 month at 27° (*794*). Dates of the soft, invert-sugar type should be stored at −18° or lower. At temperatures near 0°, they develop sugar spots and darken in a few months. Sugar spots impair the appearance and texture but are harmless. They can be removed by warming, but they will reappear if unfavorable conditions prevail. Soft dates should keep satisfactorily for 1 year at −18° and about 6 months at 0°.

Deglet Noor dates stored in pallet boxes should be packed no more than 60 cm (2 ft) deep and should contain no more than about 22 percent moisture (*797*).

(See also *791, 792, 793, 796, 798, 828*.)

Figs, Fresh

(Temperature, −0.5° to 0°C) (31° to 32°F); relative humidity, 85 to 90 percent)

Fully mature fresh figs are soft, easily bruised, and highly perishable. Mission fig, a black fig with distinctive flavor, and Calimyrna fig, a large yellowish fig, are the main cultivars sold fresh. For maximum life, the fruit should be precooled immediately after havest to near 0°C and placed at a temperature of −0.5° to 0° and relative humidity of 85 to 90 percent. These conditions will allow a marketing period of 7 to 10 days (*790*). An atmosphere enriched with carbon dioxide has been suggested as a supplement to refrigeration (*117*). Common market diseases of figs are alternaria rot, aspergillus rot, and soft rot. Alternaria spotting that may start while figs are on the tree and continue to develop in storage, especially at near 10°, greatly detracts from the appearance of the fruit.

(See also *164, 481.*)

Grapefruit

(Temperature, 10° to 15.5°C (50° to 60°F), see text; relative humidity, 85 to 90 percent)

Decay and rind breakdown, which may develop in fruit during storage or after removal from storage, are deterrents to long storage of grapefruit. Stem-end rot is especially destructive to fruit grown in Florida, but it is of minor importance in arid States, such as California and Arizona. Florida grapefruit that have been degreened with ethylene or are overripe should not be stored because of their susceptibility to stem-end rot. Blue mold and green mold rots are serious diseases on grapefruit from all producing areas.

Grapefruit are seldom stored for more than a few weeks. However, grapefruit that are sound, have been carefully handled, and are not overripe can usually be stored 6 to 8 weeks without serious spoilage at the recommended temperature. Researchers in Israel (*813*) have reported that waxed and fungicide-treated Marsh Seedless grapefruit stored successfully for 16 weeks at 12°C and had a 2-week shelf life at 17°.

The selection of a proper temperature for storing grapefruit should be based on preharvest factors—including weather during growth, tree condition, and orchard treatments—as well as ripeness of the fruit, postharvest handling, and length of proposed storage. A temperature range of 10° to 15.5°C is recommended for storage of grapefruit. Early harvested grapefruit in Florida and Texas are chilling sensitive and should be stored or shipped at 15.5° (*614*). The temperature may be reduced to 13°, then 10° for later pickings as the fruit become more mature (January to March). Late-season grapefruit picked from trees with new spring growth (April to May) usually are not suitable for extended storage.

Grapefruit are very susceptible to chilling injury at storage temperatures below 10°C. Watery breakdown, brown-staining, and rapid development of decay upon removal from storage become serious when grapefruit are held at 0° for more than 2 to 3 weeks. Rind breakdown, such as pitting and aging, becomes more prevalent at 4° than at higher or lower temperatures.

Relative humidity should be maintained at 85 to 90 percent with all temperatures. Lower humidities favor rind breakdown. Actually, a relative humidity of 90 to 98 percent is good for grapefruit in wooden containers. Waxing is very desirable to minimize moisture loss (*148, 1007*).

Stem-end rot and green mold rot may develop in the packinghouse, in transit, in storage, and in the market, but they can be greatly reduced if fruit are properly treated with approved fungicides such as sodium *o*-phenylphenate, thiabendazole, benomyl, or 2-aminobutane (*614*). The use of biphenyl-treated pads is also advantageous. Thiabendazole and benomyl have also been shown to reduce peel pitting due to chilling injury (*812*). However, strains of blue and green mold fungi can develop resistance to these benzimidazoles; thus, when used for long periods on citrus, these chemicals become ineffective for decay control (*405*).

Precooling is used to only a minor extent with Florida citrus, usually by room precooling. Precooling can be harmful to early-season grapefruit because of chilling injury that results in severe peel injury. Hydrocooling may increase peel injury and should not be used.

Grapefruit quality does not improve in storage. The longer the storage period, the greater will be the loss of juice and flavor; also, rind breakdown and decay increase in proportion to the length of the storage period.

Sometimes degreening of the rind before marketing may be necessary. Recommendations are to use 1 to 5 p/m of ethylene in a room kept at 28° to 30°C and 90 to 96 percent relative humidity (*1007, 1008*). Fresh air should enter the room at a rate of one air change per hour, based on the volume of the empty room. Air circulation within the room should be at least 2.8 m^3 (100 ft^3)/minute/pallet box. This air flow rate is necessary to maintain uniform temperature, ethylene concentration, and humidity at the surface of each fruit in the degreening room. The duration of treatment is usually 1 to 3 days. Some natural degreening occurs during storage.

Research has shown that conditioning or curing counteracts some of the adverse effects of low-temperature storage. Prestorage conditioning of Marsh and Ruby Red grapefruit for 7 days at 16° or 21°C was effective in reducing chilling injury during subsequent storage for up to 21 days at 1° (*373*). If grapefruit are preconditioned this way, they can be successfully stored or shipped (exported) with oranges at low temperatures. Cold-injury spotting of California-grown Marsh grapefruit was reduced by 3 weeks' holding at 11° before storage at 0° and 5° (*361*).

Interest has increased in shrink wrapping individual grapefruit (unipack) in polyethylene film to extend storage life. Grapefruit sealed in film lost much less weight and flavor and remained firmer than non-

wrapped fruit (*83, 462*), but decay increased when fruit were both waxed and film wrapped (*310*). Grapefruit in unipacks also developed less chilling injury during low-temperature storage. Unipacking may become a useful supplement to refrigeration. It may allow some shipments without refrigeration or humidity control, thereby saving energy.

Controlled-atmosphere storage has been found to be of little or no advantage for extending the storage life of grapefruit. In some tests atmospheres containing 10 percent carbon dioxide markedly reduced pitting over that occurring on grapefruit stored in air for 3 weeks at 4.5°C (*372*). However, control of pitting with carbon dioxide has been inconsistent. In other tests, stem-end rind breakdown, a physiological disorder, was reduced in fruit held at 4.5° for 8 and 12 weeks when pretreated with 20 or 40 percent carbon dioxide for 3 or 7 days at 21°. Researchers concluded, most importantly, that no combination of reduced oxygen or increased carbon dioxide levels which maintained fruit quality prevented subsequent decay (*888*).

(See also *277, 652, 779*.)

Grapes

Vinifera Grapes

(Temperature, −1° to −0.5°C (30° to 31°F); relative humidity, 90 to 95 percent)

Large quantities of vinifera table grapes, grown principally in California, are stored annually. Grapes, unlike apples and pears, do not continue to ripen after harvest, so they should be harvested at optimum maturity. Harvesting should not be delayed after full maturity is reached. For maximum storage life, grapes should be precooled after harvest by forced-air cooling or by tunnel cooling. A minimum air volume of 170 m^3 (6,000 ft^3)/minute/1,000 lugs is recommended for room precooling.

A temperature of −1°C is recommended for storage of grapes. Most grape cultivars do not freeze at −2°, but stems and individual, immature berries that are low in soluble solids may freeze slightly at this temperature.

High relative humidity is necessary to minimize moisture loss and maintain stems in good condition. When grapes lose 1.2 percent or more water by weight, their appearance is adversely affected. A relative humidity of 90 to 95 percent is recommended. The present trend is to store them at the higher humidity levels. High humidity in a mechanically refrigerated storage is best maintained by careful control of refrigerant temperature or by the use of a spray humidification system.

Grapes deteriorate in storage by decay or natural aging or by chemical, physical, or mechanical injury. Gray mold (*Botrytis cinerea*) is the most common cause of spoilage. Cladosporium rot and alternaria rot are also important diseases of grapes. Grapes harvested after rains are much more subject to decay than those harvested after a dry period.

Vinifera grapes are fumigated with sulfur dioxide (SO_2) soon after harvest and at intervals during storage to reduce spoilage caused by decay organisms. Initially, an SO_2 concentration of 0.5 percent is applied for 20 minutes just before or during precooling. A 0.25-percent concentration is used at weekly or 10-day intervals during storage. After the 20-minute gas treatment, SO_2 is usually purged from the room to quickly reduce the concentration to levels that will not injure the fruit or personnel who must reenter the room. The gas is removed either by an exhaust fan, by passing the storage air through a water-spray system, or by use of portable scrubbing units (*660*). Just before shipment, grapes are usually refumigated in the cars or trucks. The toxicity of SO_2 to *Botrytis* and *Alternaria* spores is increased substantially by high relative humidity (*173, 177*). Excess fumingation can result in SO_2 injury, which is characterized by bleaching of the skin of the fruit around the cap stem or pitting and bleaching over scattered small areas of affected berries. Sulfur dioxide is very corrosive to metal; therefore, coils are often coated with corrosion-resistant paints or oils, and some method of bypassing the coil during fumigation is provided.

Fruits other than grapes should not be in the storage room during treatment with SO_2, as this chemical is injurious to most other fruits and vegetables.

Sodium bisulfite packets placed in the containers with grapes can substitute for the fumigation treatment during several weeks' transit. Packets are formulated to release SO_2 either immediately or several days later, and generally both types of packets are placed in the container for longer lasting effect. Pallets holding containers with SO_2 packets can be covered with polyethylene film to maintain high relative humidity. The rate of SO_2 released by these materials is greater at higher temperatures, but the concentration of SO_2 in the container is maintained longer at lower temperatures (*661*). The release of SO_2 from packets cannot be carefully regulated, and injury has resulted from high concentration in some studies.

Sulfur dioxide kills fungus spores present on the surface of the fruit, but it does not kill infections that were present before storage. By using a decay forecast, a storage operator can market early in the season those lots of grapes that show a likelihood of developing a high percentage of decay and hold for long storage those with low decay potential (*363*).

Vineyard applications of fungicides have been effective in reducing field infections and decay in storage.

Controlled atmospheres or use of carbon monoxide is effective in maintaining the shelf life of the grapes but not in controlling decay (*1075*).

Aging, which indicates that the grapes are approaching the end of their storage life, is manifested by the berries losing their brightness and acquiring a soft and flaccid texture. Red cultivars become gray-purple and green cultivars turn gray-green to brown.

Storage life differs with cultivar. Thompson Seedless, the most popular cultivar, will store for 1 to 2.5 months. Ribier should keep 2 to 4 months. Late-season cultivars

Emperor, Ohanez (Almeria), and Calmeria will keep for 3 to 6 months. Storage life is dependent on maturity at harvest, precooling, an effective fumigation program, and low constant-storage temperature (*384, 790*).

Escaping ammonia will turn red grapes blue, and green-colored fruit bluish. Fruit will not recover from severe injury. The ammonia can be best removed from a storage room with water. Sulfur dioxide also can be used to minimize damage from ammonia (see p. 27).

A comprehensive discussion of the storage of vinifera grapes, including a description of and methods to control various storage disorders, is contained in *788, 790*.

(See also *367, 662*.)

American Grapes

(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 85 percent)

The eastern, or American, cultivars of grapes (Labrusca) are not adapted to long storage. These grapes are excellent for table use, but most are now used for fresh juice, jellies, and wines. Concord, the most important cultivar, can be stored 4 to 7 weeks at 0°C. After that the grapes begin to deteriorate in flavor, and considerable decay and shattering may develop, particularly if the temperature is not kept close to 0°. Neither 2° nor 4° is as acceptable for more than a few days (*549*). Delays of 1 to 5 days before storage at 0° greatly increase shatter of berries and decay. Catawba and Delaware grapes keep better than most other eastern cultivars; if in good condition when stored, they can be held 5 to 8 weeks. Grapes intended for storage should be handled carefully to prevent cracking or loosening at the cap stem. Prompt cooling is also important for best results. American grapes are not fumigated with sulfur dioxide because of their susceptibility to injury (*549, 942*). However, sulfur dioxide releasing pads are used for decay control in the storage of Concord grapes in the Northeastern States.

Low humidities are undesirable for grapes, since they cause shriveling of stems and berries. A relative humidity of about 85 percent is recommended. Very high humidities favor decay and shattering. A positive airflow between packages is desirable to reduce decay, but it results in more shriveling, weight loss, and poorer stem color (*97*).

Muscadine grapes do not keep nearly so well as the Labrusca type. Scuppernong and Thomas cultivars will remain in good condition for 2 to 3 weeks at 0°C. Other cultivars tested did not keep as well as Scuppernong or Thomas cultivars (*549*). However, muscadine grapes picked mechanically, cleaned and sorted, and then packed in cellophane bags to await processing kept satisfactorily for 2 months at 0° in the presence of sulfur dioxide (*843*). This procedure could not be successfully applied to some cultivars of muscadine grapes (*61*). For grape diseases see *367*.

Guavas

(Temperature, 5° to 10°C (41° to 50°F); relative humidity, 90 percent)

Guavas for fresh use or for making jellies, preserves, and similar products can be stored 2 to 3 weeks at 5° to 10°C and 90 percent relative humidity. At temperatures below 5°, guavas are chilled; and chilling can result in pulp injury and decay (*1044*).

Kiwifruit

(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Kiwifruit, formerly called Chinese gooseberries, a vine crop, have good keeping qualities. Usual storage life is 3 to 5 months at −0.5° to 0°C with 90 to 95 percent relative humidity. Some California kiwifruit can be stored for as long as 8 months. Fruit picked late in the harvest season may not store longer than 2 months. The fruit should be forced-air cooled to −0.5° to 0° within 8 to 12 hours after harvest and held at this temperature both prior to and after packing. After cooling, adequate air circulation is essential in storage to avoid cold or hot spots.

Packaging is in single-layer trays with perforated polyethylene liners in wooden or corrugated cartons. The polyethylene maintains high relative humidity and allows a small percentage of carbon dioxide to build up, which aids long-term storage.

Fruit soften slowly in storage at 0°C, and softening is accelerated if ethylene gas is present. Even very low concentrations of ethylene (0.1 p/m) will cause premature ripening in storage. It is essential that anything that produces ethylene, such as apples, be kept away from the kiwifruit storage area; otherwise long storage will not be possible (*54, 249, 351*).

Ripening, if necessary after storage, is done at room temperature (18° to 21°C). Ethylene gas can be added to hasten ripening at the market, as done for bananas. Signs of spoilage of kiwifruit are excess softening, shriveling, and mold.

Controlled-atmosphere storage (CA) allows maximum storage life. Kiwifruit in CA of 5 percent carbon dioxide with 2 percent oxygen at 0°C maintain firmness 6 to 8 months and then ripen to good eating quality (*630*). However, the presence of ethylene under CA conditions can negate the positive benefits and enhances flesh softening. Carbon dioxide levels of 10 percent in storage may injure kiwifruit.

Lemons

(Temperature, see text; relative humidity, 85 to 90 percent)

Lemons are picked during any month of the year, but most fruit reach picking size and must be picked during the winter, when consumption is relatively light. Fortunately, fruit picked during this time have the capacity to endure storage for several months. In fact, storage improves fruit quality, allowing the lemons to better withstand shipping and marketing operations. Most lemons are not ready for consump-

tion immediately after harvest but need conditioning to develop color, juice content, and flavor. Conditioning is customarily done in refrigerated warehouses maintained at 13° to 15.5°C and 85 to 90 percent relative humidity. Ventilation is provided to remove ethylene and possibly other metabolic products produced by molds and by the lemons themselves (*359*). Lemons in ventilated storage should keep 1 to 4 or sometimes even 6 months. They lose weight at a rate of 2 to 3 percent per month (*799, 802*). Experience has shown that during long storage at temperatures much below 14.5°, pitting, staining of the membranes separating the segments, and red blotch may sometimes develop. Temperatures higher than 15.5° favor the growth of decay organisms and shorten the storage life. Lemons that are of proper size and dark-green color when picked have the longest storage life. Tree-ripened, yellow fruit do not keep well in storage and should be marketed immediately. Lemons from different production areas have different keeping qualitites.

Storage at terminal markets often involves considerable risk, as most of the storage life may have been used up before shipment and the fruit may be especially subject to decay. Therefore, knowledge of the previous history of the lemons is desirable. Only lemons of good storage potential should be held for extended periods at terminal markets. For less than 4 weeks' storage, such lemons can be held at any convenient temperature from 7° to 13°C, but for longer periods, 11° to 13° is recommended because of the danger of pitting and membranous stain at the lower temperatures (*219, 360, 362, 1036*).

A low oxygen concentration of 5 to 8 percent in the storage atmosphere can reduce decay and delay the color change (*89, 295, 803*). However, if oxygen falls below 3 percent or if carbon dioxide rises above 10 percent for a prolonged period, adverse effects on flavor may occur. Removal of ethylene from the atmosphere can also reduce mold development (*1035*).

It is of the utmost importance that lemons be handled carefully during picking and packing to avoid clipper cuts, scratches, and bruises and consequent decay later by *Penicillium* (green mold rot and blue mold rot). The fungus that causes blue mold rot is able to penetrate the uninjured skin of lemons, but it is likely to cause greater loss if the skin is broken. It can also spread from one fruit to another in the package; for this reason it is frequently referred to as "blue contact rot." Soda ash, borax, benomyl, or thiabendazole treatment in the wash water or incorporated in the wax applied after washing is recommended to aid in control of decay (*889*). Sodium *o*-phenylphenate (SOPP) is not recommended for lemons going into storage, because a residue in the rind is likely to result in a buildup of strains of *Penicillium* that are resistant to both SOPP and biphenyl (*347*). However, SOPP may be applied to lemons after storage and before shipping to help reduce decay during transit and marketing. Lemons packed for the market nearly always contain biphenyl sheets—one in the top and one in the bottom of the container—to aid in decay control (*804*).

Alternaria rot is often serious in lemons, usually entering the fruit through the buttons. The decay seldom invades lemons showing green buttons, so the condition of the button is a criterion of susceptibility to alternaria rot (*359*). Lemons destined for storage are usually treated with 2,4-D—a treatment that delays the darkening of the buttons and subsequent decay by *Alternaria* (*208*).

Limes

(Temperature, 9° to 10°C (48° to 50°F); relative humidity, 85 to 90 percent)

For best quality, the Tahiti (Persian) lime should be picked while still green but after the skin has become smooth and the fruit mature and somewhat rounded. Tahiti limes can be stored satisfactorily at 9° to 10°C for 6 to 8 weeks; however, some loss of green color becomes apparent after 3 to 4 weeks' storage. After 8 weeks' storage the rind is often yellow-green (*942*). Green color is retained better at 4°, but limes are subject to pitting at temperatures of 7.5° and below. This condition develops soon after removal from storage. Under aggravated conditions the pits may coalesce and form leathery, brown, sunken areas on the rind. Chilling injury drastically limits the storage and marketing of limes. The extent of chilling injury resulting from holding limes at 4° can be reduced by keeping the relative humidity near 100 percent (*689*).

The relative humidity during storage at 9° to 10°C should be kept at 85 percent to 90 percent, and the fruit should be waxed to prevent moisture loss and desiccation. Limes have little or no natural cuticle to retard moisture loss.

Stylar-end breakdown of Tahiti limes, a physiological disorder of the blossom end, which is often followed by invasion of decay pathogens, is a most serious problem in handling (*297, 374*). It can be prevented by avoiding bruising and by prompt refrigeration at 10°C. Oil gland injury (oleocellosis) associated with bruising causes a pebbly, brown to black rind discoloration.

Key (Mexican or West Indian) limes can be stored satisfactorily at the temperatures recommended for Persian limes. The usual color for Key limes on the markets is yellow.

Controlled-atmosphere storage has not been used commercially for limes. However, Tahiti limes stored experimentally for 6 weeks at 10°C and a low pressure of 170 mm Hg retained their green color and flavor better than fruit stored at normal atmospheric pressure (*900*).

(See also *223, 889*.)

Loquats

(Temperature, 0°C (32°F); relative humidity, 90 percent)

Loquats, consumed largely as fresh fruit, are harvested when fully ripe but still firm. Recommended storage conditions for up to 3 weeks are 0°C and 90 percent relative

humidity. Storage at 0° causes the least internal browning, weight loss, and shriveling (*303*). Use of polyethylene bags will retard weight loss.

Lychees

(Temperature, 1.5°C (35°F); relative humidity, 90 to 95 percent)

Darkening, desiccation, and decay limit the storage of fresh lychees. Lychees can be stored 3 to 5 weeks at 1.5°C if packaged in polyethylene bags or similar moisture-retentive material to prevent desiccation. Lychees are susceptible to chilling injury, and 4° has been reported to be a chilling temperature (*243*). However, the combination of high relative humidity and self-perpetuated modified atmosphere within the polyethylene bags can increase chilling resistance. At 7°, lychees in polyethylene bags will keep satisfactorily for 2 weeks (see *10, 137*); however, peel color is retained best at 10° (*378*).

Mangos

(Temperature, 13°C (55°F), see text; relative humidity, 85 to 90 percent)

The best storage temperature for mangos is 13°C; they should keep for 2 or 3 weeks at this temperature. Some mango cultivars, such as Irwin and Tommy Atkins, store successfully for as long as 3 weeks at 10°; but other cultivars, such as Haden and Keitt, are susceptible to chilling injury at this temperature. At temperatures below 10°, all immature mangos are highly susceptible to chilling injury. This is manifested as a grayish scaldlike discoloration of the skin, the discoloration often being accompanied by pitting, uneven ripening, and poor flavor and color development (*377, 453*).

The best ripening temperatures for mangos are 21° to 24°C; higher temperatures often result in abnormal flavors. Temperatures of 15° to 18° accentuate color development of the skin but result in fruit with a tart flavor; such fruit must be allowed to ripen an additional 2 or 3 days at 21° to 24° to develop full sweetness. Ethylene can be used to speed ripening of mangos (*257*).

Decay, especially anthracnose and sometimes diplodia stem-end rot, is often widespread. For extended storage, fruit should be periodically checked for the presence of decay. Immersing mature-green fruit in hot water will retard anthracnose development during storage (*890*). It has been shown that low-pressure (hypobaric) storage delays ripening, reduces decay, and extends shelf life of mangos (*901*).

(See also *14, 933, 943*.)

Olives, Fresh

(Temperature, 5° to 10°C (41° to 50°F); relative humidity, 85 to 90 percent)

Fresh olives can be safely stored at 5° to 10°C for 4 to 6 weeks. At temperatures above 10° olives ripen and shrivel; and at temperatures below 5°, they are susceptible to chilling injury. In chilling injury, the flesh of green fresh olives become brown, beginning around the seed and at the stem end. Ripe fresh olives develop more browning than green ones. Browning in its early stages can be detected only by cutting the fruit. Olives for processing have been successfully stored for 3 months at about 5° (*597*). (See also *598*.)

Oranges

(Temperature: Florida and Texas, 0° to 1°C (32° to 34°F); California and Arizona, 3° to 9°C (38° to 48°F), see text. Relative humidity: 85 to 90 percent)

Most commercial cultivars of oranges go directly to the fresh-fruit market or to processing plants. Usually storage is not required for fruit going to processing plants; and only short-term storage is needed for orderly distribution and marketing, because fruit are available year round from one or another of the producing areas. In Florida, less than 10 percent of the oranges are marketed fresh, while in California about 65 percent are marketed as fresh fruit. The Valencia, a late cultivar in all producing areas of the United States, is harvested over a relatively long season and is the primary cultivar stored. Most early-season fall and winter cultivars do not store as well as the Valencia, and the Navel cultivar will develop off-flavors during long storage. The successful storage of oranges demands that fruit be of prime maturity when picked and carefully handled during all operations. When transported long distances to terminal storages, oranges must be adequately precooled and refrigerated in transit.

Orange quality does not improve in storage. Oranges ordinarily deteriorate faster in storage than if left on the tree under normal weather conditions. In addition, the fruit are subject to several kinds of decay and other disorders that may develop during storage. Florida and Texas oranges are particularly susceptible to stem-end rots, especially during the early degreening season. Fruit from all sections are subject to blue mold and green mold rots. Decay will be greatly reduced if oranges are treated with an approved benzimidazole fungicide alone or with other fungicides such as sodium *o*-phenylphenate (SOPP), 2-aminobutane, or imazalil. Biphenyl-treated pads have also proved advantageous. A combination of these treatments is suggested for maximum benefit and to avoid development of fungal strains resistant to certain fungicides (*405, 614, 889, 1007*).

Stem-end rind breakdown or aging is the most common physiological disease of oranges. It can be minimized by prompt handling, avoidance of excessive brushing, maintenance of high humidity during degreening, and prompt application of an even wax coating to protect against moisture loss (*189, 613, 1007*).

Florida- and Texas-grown Valencia oranges can be stored successfully with a minimum of decay and rind pitting for 8 to 12 weeks at 0° to 1°C, with a relative humidity of 85 to 90 percent and forced-air circulation. The same recommendations apply

to Pope's Summer orange, a late-maturing Valencia-type orange (*33, 148, 293, 787*). The flesh and juice quality of Valencia fruit stored at 0° to 1° is so much better than that stored at higher temperatures that minor rind defects due to low-temperature storage do not have commercial significance.

California and Arizona oranges are chilling sensitive and more subject to rind disorders than Florida or Texas oranges at low temperature. A temperature of 5° to 7°C is suggested for most California oranges. However, Arizona Valencias may be injured even at this temperature. A temperature of 9° has been found best for Arizona oranges harvested in March, and that of 3° for fruit harvested in June (*465*). Depending upon State of production and time of year, California and Arizona Valencias should keep 6 to 8 weeks at 3°, 4 to 6 weeks at 5° to 7°, and 3 to 4 weeks at 9°. Blue mold and green mold rots may become serious at these higher temperatures. Stem-end rots are not a problem on western citrus. Susceptibility to rind disorders varies from season to season and from grove to grove. California Navel oranges are sometimes stored 2 to 6 weeks at 5° to 7° to allow orderly marketing.

Degreening with ethylene to remove the chlorophyll from the peel may be needed for some oranges before marketing. Degreening is accomplished by maintaining no more than 5 p/m of ethylene in the room air at a temperature of 28° to 29°C and 90 to 96 percent relative humidity for Florida oranges. In California, the process of degreening is called sweating, and 18° to 21° is preferred. Fresh air should enter the room at the rate of one air change per hour, based on the volume of the empty room (*1008*). With good air circulation within the room, degreening should be accomplished in 1 to 3 days. Degreening increases susceptibility to decay, particularly if the concentration of ethylene is high or the duration of the treatment is excessive.

Precooling is usually accomplished by refrigerated air in specially designed precooling rooms after the fruit are packed. Experimentally, much more rapid cooling has been obtained by forced-air precooling of oranges placed on a moving conveyor using air at −7° to −4°C, considerably below the freezing point of the fruit (*292*). Showering oranges with 0° water for 20 minutes (hydrocooling) can lower pulp temperatures by 11° to 14°, but currently this is not done.

Much fresh market citrus is now marketed prepackaged or consumer packaged in polyethylene bags, in plastic mesh bags, or in shrinkable film used as an overwrap. These are marketing containers and normally should not be used for storing oranges. Film bags must be perforated with many holes so that the humidity does not build up sufficiently to promote decay (*291, 460*). Fruit to be prepackaged should be precooled and treated with fungicides to minimize spoilage during subsequent refrigerated handling and transport.

Oranges should not be stored with eggs, apples, cheese, or butter nor in places where orange odor or biphenyl odor might penetrate into egg, cheese, or butter storage rooms.

Oranges in storage should be examined often for pitting or decay. After such examinations, any decision on how long the fruit can safely be left in storage should be based on the fact that if pitting and decay are present, they will increase rapidly after the fruit are removed to higher temperatures.

Controlled-atmosphere storage (CA) has not been successful for oranges. Atmospheres used successfully for apples are unsatisfactory for oranges and lead to rind injuries, off-flavors, and decay. Low concentrations of carbon dioxide (2.5 to 5.0 percent) adversely affected flavor retention, particularly when combined with 10 or 5 percent oxygen. Florida Valencia oranges stored in 15 percent oxygen with 0 or 5 percent carbon dioxide for 12 weeks at 1°C following by 1 week at 21° retained better flavor and had less rind pitting than fruit stored in air (*147*). However, CA did not control subsequent decay (*372, 615*).

When ethylene is removed from the storage atmosphere, there is less stem-end decay and less loss of desirable orange flavor during storage (*615*). Ethylene can be removed by venting fresh air into the storage rooms.

(See also *218, 277, 346, 652*.)

Papayas

(Temperature, 7°C (45°F); relative humidity, 85 to 90 percent)

Hawaiian papayas for shipping are harvested at the 3/4-ripe color stage and treated for insect and decay control. Since papayas are subject to chilling injury, they should be held at a temperature close to but not below 7°C. Papayas should keep satisfactorily for 1 to 3 weeks at 7° and should be ripened at 21° to 27°, as needed, for the retail market.

Anthracnose, the principal decay, and other decays are fairly well controlled by applying heat by one of two methods—vapor-heat treatment or hot-water treatment. Both are about equally effective. In the vapor-heat treatment, papayas are exposed to a hot saturated atmosphere until the center of the fruit reaches 47°C. A preliminary conditioning at about 43° and 35 percent relative humidity for 6 to 8 hours is necessary to increase the tolerance of the fruit to the vapor-heat treatment. The hot-water method consists of dipping the fruit in hot water at 47° for 20 minutes.

A double-dip hot-water treatment is recommended for disinfestation of fruit flies and is used in place of ethylene dibromide fumigation on papayas sent to the mainland. In the double-dip treatment, papayas are dipped in 42°C water for 30 minutes and then in 49° water for 20 minutes. This treatment protects against anthracnose and disinfests the fruit of fruit flies. Currently, only one-fourth ripe fruit are required to have this treatment.

An atmosphere high in carbon dioxide (10 percent) discourages decay development of papayas held at 18°C but is not a substitute for the hot-water treatment (*897*). Hypobaric atmosphere (20 mm Hg) inhibits ripening and decay, and papayas ripen normally after

removal from hypobaric atmosphere; but abnormal softening unrelated to disease has been noted with some fruit (*29*). Nearly all Hawaiian papayas are now shipped to the mainland by air (*20*). (See also *11, 1004.*)

Peaches and Nectarines

(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Peaches and nectarines are seldom stored except for a short period to carry them over a glut in the market or to extend the processing season. In general, sound, well-matured fruit can be stored 2 to 4 weeks at −0.5° to 0°C, depending upon the cultivar and growing season (*321, 322, 633*). Early peaches have a very short life. Late cultivars, such as Rio-Oso-Gem, may keep 4 to 5 weeks. Clingstone peaches can be held up to 4 weeks to lengthen the canning season. Peaches that are held longer than 3 to 4 weeks in cold storage often fail to ripen satisfactorily on removal to higher temperatures. Their flesh may become dry and mealy, or wet and mushy, and may brown markedly, especially around the stone. Flavor deteriorates as well, and the appearance is dull rather than bright. This aging has been called internal breakdown, mealy breakdown, or woolliness. The extent of internal breakdown can be reduced by preripening fruit for 1 to 3 days at 21° to 24° before placing them in cold storage. Internal breakdown may also be reduced by removing fruit to room temperature (21° to 25°) for 48 hours after 2 and 4 weeks' storage at 0° (*37, 76*). Storage in a controlled atmosphere, described later, will also reduce internal breakdown and allow longer storage (*41, 685*). Internal disorders caused by improper storage often are not apparent until peaches are examined after ripening.

Storage of peaches and nectarines at 2° to 5°C is especially bad as internal breakdown, which may be initiated at these temperatures in as little as 7 to 14 days, will develop during ripening (*37, 322, 633*). These fruit also have poorer flavor. Shifting fruit from 0° to 5° after 1 or 2 weeks' storage is also a poor practice, as it will result in very severe internal breakdown. Research has shown that breakdown in these fruit may be as severe as in fruit stored continually at 5° (*37*). No internal breakdown develops at 10°, but this temperature is unsatisfactory because of rapid flesh softening (*633*).

Peaches ripen satisfactorily at temperatures between 18° and 29°C. Ripening and softening of the flesh are rapid at 18° and above. However, ripening at 18° generally results in less decay than ripening at higher temperatures. Practically no softening of peaches will occur in properly stored fruit at 0° (*321, 322*). Peaches harvested at the firm-ripe stage and destined for processing often need 4 to 6 days for ripening. Research has shown that storage for 10 to 14 days at −0.5° to 0° will measurably reduce rhizopus decay during subsequent ripening but will have little effect on brown rot (*368, 719*). Generally, peaches are of better quality and have less decay when they are ripened after storage than when they are ripened before storage. Peaches softened at room temperature will reharden to some extent when returned to low-temperature storage (*1026*).

Rapid cooling of peaches and nectarines after harvest to temperatures below 4°C is important to retard respiratory activity, ripening, and decay. A common fault is failure to cool fruit to low enough temperatures for adequate protection. On the basis of respiratory activity, 1 day at 21° to 27°C is equal to 2 days at 15°, 4 days at 10°, 8 days at 5°, and 16 days at 0° (*322*). Hydrocooling is the usual precooling method for eastern-grown fruit, while forced-air cooling is more common in the West. A newer method, called hydraircooling, combines the advantages of hydrocooling and air cooling, while minimizing their respective disadvantages (*81*). Hydraircooling involves the circulation of cold air through a mist of cold water that is sprayed into the airstream as it impinges upon the fruit. A regular hydrocooler operating properly takes a little more than 30 minutes to cool 3-inch peaches from 32° to 4° in 1.6° water and about 15 minutes to similarly cool 2-inch peaches (*80*). For fast cooling, hydrocooling is best. However, hydrocooling should not be used after waxing or treatment with a fungicide, as it will wash the wax and fungicide off the surface and possibly recontaminate the fruit with decay-producing microorganisms. Neither hydraircooling nor forced-air cooling will remove significant amounts of wax coating or of fungicide incorporated in a wax. Waxing prevents excessive weight loss from peaches and nectarines during storage and marketing (*81, 1023, 1025*).

Nectarines are more susceptible to shriveling than peaches, so for nectarine storage the air velocity should be as low as possible while still maintaining proper temperature. Shrivel becomes visible when weight loss reaches 4 to 5 percent (*268*). Useful supplements to protect nectarines include wax and moisture-barrier packing materials such as polyethylene liners or curtains and plastic trays (*632*).

Brown rot is the most important disease of peaches and nectarines. Refrigeration after harvest is the most common method of control. Temperature studies have shown that as much brown rot develops in peaches held 1 day at 24°C as in peaches held 7 days at 5° or 25 days at 0° (*368*). Treatment with postharvest fungicides is usually necessary to reduce decay losses during storage and marketing. A systemic fungicide residue on the fruit, such as benomyl, will reduce infections (*393, 711, 1023*).

Brief dips in hot water reduce both brown rot and rhizopus decay when the decay organisms are either on the surface or under the skin. A dip for 2½ minutes in 52°C (125°F) has been recommended for decay control of freshly harvested peaches (*867, 868*). Frequently, however, some skin injury develops; therefore, temperature control is critical (*710, 868*). A better treatment for peaches and nectarines to be stored is a 2½-minute dip in 46°

(115°F) water containing 100 p/m benomyl. This treatment has effectively controlled decay during storage at 0° and ripening at 18° without causing injury (*866*). Good sanitation practices are very important during precooling, storage, and packaging of stone fruits.

Controlled-atmosphere storage (CA) can extend storage life by retarding internal breakdown and maintaining dessert quality of peaches and nectarines for up to 6 to 9 weeks at 0°C. Researchers found that a CA of 1 percent oxygen with 5 percent carbon dioxide should allow fruit storage for twice as long as fruit storage in air (*41, 42, 636, 760*). Other researchers preferred 2.5 percent oxygen with 5 percent carbon dioxide to allow storage of nectarines for 6 weeks (*685*). The beneficial effect of CA is largely from the 5 percent carbon dioxide rather than from the low oxygen. CA storage is of little value in preventing decay development, so a supplemental postharvest fungicide treatment is needed. Recent tests on intermittent warming combined with CA storage have shown promise to give maximum storage life. At 3- to 4-week intervals the fruit are warmed 2 days at 18° in air and then returned to 0° CA conditiions (*38, 42*)

Hypobaric storage is another possible method of retarding deterioration of peaches in the future (*807*). Currently, it is not economically feasible. Commercial use of CA for peaches is still limited to holding small quantities awaiting processing. Good control of decay following extended storage at 0°C and during ripening is still a problem.

Pears

(Temperature, – 1.5° to – 0.5°C (29° to 31°F); relative humidity, 90 to 95 percent)

Pears are very sensitive to temperature. The storage life of Anjou and Bartlett pears has been reported to be 35 to 40 percent longer at – 1°C than at 0° (*725*). Most pears in the Pacific Northwest are stored at – 1° with a relative humidity in the range of 90 to 94 percent (*330*). Many operators of pear storage rooms use thermocouples in the air and in fruit to determine temperatures at selected areas in the storages. Precise temperature control is needed to prevent freezing when pears are stored at these low temperatures (*354*). Rapid removal of field heat and prompt cooling of harvested pears are essential for long storage. During the pull-down period, room temperatures of – 3.5° to – 2.0° can be used but should be raised to – 1° as soon as the fruit temperatures approach – 1° (*330*). Delay in cooling shortens the storage life. It has been suggested that the core temperature should be reduced to near the holding temperature in 4 days (*726*). When pears are packed in cartons before cooling, the cartons should be stacked to provide exposure of the sides to airflow (*806*).

Pears lose moisture rapidly; hence, it is advisable to hold the relative humidity to a minimum of 90 percent. Polyethylene liners are very effective in controlling moisture loss.

Intermediate temperatures of 2.5° to 10°C are harmful to some cultivars of pears. Bartletts stored in this temperature range are dry textured and of inferior flavor (*725*).

Proper maturity at harvest is important for optimum quality and long storage life. Pears harvested at full maturity tend to be the least susceptible to physiological disorders and are the best able to ripen after storage (*995*). Immature pears are more susceptible to scald, shriveling, and friction discoloration, and late-picked fruit tend to have a higher incidence of core breakdown or are more likely to show carbon dioxide injury (*330, 995*).

Among the many methods used for determining pear maturity, measuring flesh firmness by pressure testing has been regarded as the most satisfactory (*330, 995, 1041*). The recommended ranges of firmness for harvesting several major cultivars of pears and the normal storge life are listed in table 12 (*995*). Other indices of maturity, including change in ground color, corking of the lenticels, fruit finish, ease of separation, days from full bloom, heat units, and starch-iodine test, also need to be considered when determining the optimum maturity (*330, 995, 1041*). Soluble solids content is not a reliable maturity indicator but should be at least 10 percent at harvest for best quality and prevention of freezing in storage (*330*).

Table 12
Recommended ranges of firmness for harvesting and safe length for storage of several major cultivars of pears at – 1°C

Cultivar	Firmness range (newtons)[1]	Safe length of storage (months)[2]
Anjou	58-67	6-7
Bartlett	67-85	2.5-3
Bosc	62-71	3.5-4
Comice	49-58	4-4.5
El Dorado	58-67	6-7
Hardy	40-49	2-4
Kieffer	53-67	2.5-3
Packham's Triumph	58-67	5-6
Seckel	58-67	3-3.5
Winter Nelis	58-67	7-8

[1] Newtons = pound-force x 4.448 = kilogram-force x 9.807. These firmness readings based on measurements made with 8-mm-plunger-tip pressure tester on pared surfaces.
[2] Based on pears picked at proper maturity and placed promptly in air storage at – 1°C.

The keeping qualities of pears from different production areas vary. Also, different cultivars of pears respond differently to the growing season. Bartlett pears tend to ripen prematurely if the temperatures during the 4 to 5 weeks prior to harvest are abnormally cool (*1002*). Bartlett pears exposed to these cool growing temperatures soften and yellow at an accelerated rate and produce higher levels of ethylene and abscisic acid (*1003*). These pears usually are more susceptible to core breakdown and have a shorter storage life. Anjou pears will retain better ripening capacity after long storage if the hourly average temperature for each day during the 6 weeks prior to harvest is between 14 to 17°C (*620*). Anjou pears grown in cool seasons are more susceptible to friction discoloration, whereas fruit grown in warm growing seasons tend to have a higher incidence of superficial scald.

Pears should be graded and packed as soon as possible after harvest to avoid surface skin abrasions. However, if they are promptly cooled after harvest, packing can be delayed as much as 2 to 3 weeks for Bartletts and 6 to 7 weeks for Anjous (*846*).

Some winter pear cultivars require a period of cold storage before they will ripen normally at room temperature (*329*).

Pears for canning should be held in cold storage for a short time before they are ripened to improve the uniformity of ripening (*180, 233*). Bartletts should be held at about −1°C for at least 10 to 14 days.

Most cultivars of pears do not soften appreciably during cold storage; hence, they require a period of ripening at warm temperatures to develop good flavor and texture for eating.

The best ripening temperature for pears after storage is about 15° to 21°C. Higher temperatures may result in poor quality or decay. Most pear cultivars fail to soften at 30°.

The skin of pears is sensitive to the fumes from chlorine solutions used in plant sanitation or sulfur dioxide used to fumigate grapes. Before pears are placed in storage, the rooms should be thoroughly ventilated to prevent fruit damage.

The time pears can be held safely in storage at −1°C varies with cultivar, as shown in table 12. If held beyond their normal storage life, they may not ripen properly. Even though they may appear in good condition, the flesh will not soften, the skin "scalds" or turns brown, and breakdown occurs.

Polyethylene film liners will extend the storage season of several cultivars of pears by 4 to 8 weeks (*820*). Within the liners, a modified atmosphere develops that is high in carbon dioxide and low in oxygen. This atmosphere contributes to extend storage life if the levels of these two gases are in the proper range. Carbon dioxide (CO_2) should not remain above 3 percent within the liners, or core and flesh browning may develop. Five percent CO_2 can cause rather serious brown core (*327*). Usually about 100 needlepoint perforations are made in each polyethylene liner to prevent undesirable buildup of CO_2. Carbon dioxide can also be absorbed by hydrated lime packaged in envelopes and used as a pad within the liners; benefits of low oxygen are retained (*328*). Upon removal from cold storage, the liners must be opened to avoid excessive modification of the atmosphere and consequent abnormal ripening characterized by off-odors and off-flavors.

Controlled-atmosphere (CA) storage has been used successfully to extend the storage life of pears and to maintain greater capacity for ripening. The optimum and safe CA atmosphere for commercial use is 2 to 2.5 percent oxygen and 0.8 to 1 percent CO_2 (*330*). Use of short-term high CO_2 treatment has been found to improve the keeping quality of Anjou pears (*1001*). Treatment with 12 percent CO_2 for 2 weeks immediately after harvest has a beneficial effect on retention of ripening capacity. Keeping Anjou pears in a low oxygen atmosphere (1 to 1.5 percent) with 0.1 percent or less CO_2 also can maintain higher dessert quality and reduce the incidence of superficial scald after long-term cold storage (*619*).

Physiological disorders and market diseases can be reduced by appropriate prestorage treatments. Descriptions of these diseases and disorders and their control measures can be found in U.S. Department of Agriculture, Agriculture Handbook No. 376 (*718*).

Persimmons, Japanese

(Temperature, −1°C (30° F); relative humidity, 90 percent)

Persimmons can be kept for up to 3 to 4 months at −1°C and a relative humidity of 90 percent. Shriveling may become a problem during extended storage (*163*). Storage life of the Oriental persimmon, or kaki, can be extended with preharvest gibberellic acid sprays (*469*) and by packaging in sealed polyethylene bags (*939*). Long-stored fruits are susceptible to cladosporium rot.

Fruits of many persimmon cultivars are astringent, and various methods have been suggested for removing the astringency (*434*). Treating fruit with carbon dioxide is suitable because treated fruit maintain their firmness and quality after astrigency is removed. Removal of astringency is initiated by treating persimmons with 4 percent carbon dioxide (CO_2) about 2 weeks before they are taken out of −1°C storage, and the removal is completed by treating the fruit with 90 percent CO_2 at 17° for 6 to 18 hours (*75, 265*). Astringency can be removed with a CO_2 treatment at room temperature prior to storage at −1°, but storage life is reduced by holding the fruit at room temperature for several days (*220*). An ethephon solution (1,000 p/m) removes astringency but will also decrease firmness and soluble solids content (*58, 781*). (See also *790*.)

Pineapples

(Temperature, 7° to 13°C (45° to 55°F); relative humidity, 85 to 90 percent)

Pineapples are subject to chilling injury and are not adapted to long storage. The usual storage life

is about 2 to 4 weeks. Hawaiian pineapples harvested at the ½-ripe stage can be held about 2 weeks at 7° to 13°C and still have about 1 week's shelf life remaining. Ripe fruit should be held at about 7°. Mature-green fruit are particularly susceptible to chilling injury at temperatures below 10°. Harvesting pineapples at the mature-green stage is not recommended (*13*), as pineapples do not ripen after harvest. Hawaiian pineapples are commercially treated with a fungicide.

Pineapples subjected to too low a temperature take on a dull hue, develop water soaking of the flesh, darken at the core, and are particularly subject to decay when removed from storage. Black rot is the most serious decay of pineapples during transit and subsequent marketing. This decay will not develop at 7°C, but this temperature is satisfactory only for transporting and marketing fully ripe fruit.

Controlled-atmosphere storage using 2 percent oxygen at 7°C reduces the incidence of superficial mold growth on the butt and improves the appearance and marketability of the fruit (*17*). Waxing the fruit and crown of fresh pineapples with a 20 percent (v/v) paraffin-polyethylene: water mixture can reduce the incidence and severity of internal browning caused by chilling injury (*773*).

(See also *217, 889.*)

Plums, Including Prunes

(Temperature, – 0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Plums, including fresh prunes, are not adapted to long cold storage. The safe storage period differs with cultivar. Cultivars of the Damson type store better than the softer fleshed plums of the oriental cultivars. Well-matured Casselman, Climax, Eldorado, Santa Rosa, and Wickson can usually be stored satisfactorily for 4 to 5 weeks at – 0.5° to 0°C. Ripening occurs very slowly at these temperatures, but there is some loss in varietal flavor. Storage beyond 5 weeks often results in flesh browning and abnormal flavors. Plums of high soluble-solids content often keep better than those with low solids. For most cultivars, 18° is considered a good ripening temperature; some cultivars fail to ripen properly at 26.5°.

One of the most important cultivars for commercial shipping and storage is the Italian prune. At 0°C, 2 weeks is about the maximum cold-storage period at the shipping point for this fruit if a transit period is necessary before it goes on the market. After arrival at market, prunes shipped immediately after harvest can also ordinarily be held in cold storage for about 2 weeks. If held longer, there is danger that shriveling, mealiness, internal browning, and abnormal flavor will develop. However, ripening of Early Italian prunes can be enhanced by a few days' exposure to low temperature (1°). These prunes develop more color, have less acid, and are softer than prunes ripened immediately at ripening temperature without cold treatment (*741*).

Some cultivars benefit from modified or controlled atmospheres (*172, 174*). Modified atmosphere may be used to supplement low temperature during storage or transit. Storage life of plums can be extended by 1 percent oxygen at – 0.5°C with intermittent warming (*863*).

Common disorders and diseases of plums include internal breakdown, russeting, split pits, blue mold rot, brown rot, and gray mold rot. Their symptoms and control measures are discussed in *368*.

(See also *319.*)

Pomegranates

(Temperature, 5°C (41°F); relative humidity, 90 to 95 percent)

Pomegranates are susceptible to chilling injury, but because of low sensitivity they can be stored for a limited period at chilling temperatures. They can be held for 1 month at 0°C or 2 months at 5° before being injured. Storage for 6 weeks is possible at 10° (*446*). Relative humidity should be 90 to 95 percent, with 95 percent preferred for long storage to minimize water loss. Symptoms of chilling injury are surface pitting and discoloration, internal discoloration of locular septa, and increased susceptibility to decay. These symptoms are readily apparent after the fruits are transferred from the chilling temperature to 20° for a few days (*446*).

Quinces

(Temperature, – 0.5° to 0°C (31° to 32°F); relative humidity, 90 percent)

The behavior of quinces in storage is about the same as that of early cultivars of apples, such as Jonathan and Grimes Golden *(1042)*. Storage life is 2 to 3 months, and the fruit are ripened for processing at about 20°C. Although covered with a heavy fuzz, quinces bruise very easily. They are also subject to fruit rots similar to those found on apples and pears (*718*). Treatment with fungicides is necessary to prevent decay during storage.

Tangerines, Mandarins, and Related Specialty Citrus Fruits

(Temperature, 4°C (40°F); relative humidity, 90 to 95 percent)

Specialty citrus fruits, which are usually eaten out of hand, include Temples, tangerines, tangelos, Honey tangerines (formerly Murcotts), and other mandarin-type fruits. Adequate precooling and continuous refrigeration are required. Careful handling from tree to consumer is necessary. Because they are perishable, these fruits should not be stored longer than required for orderly marketing, 2 to 4 weeks, and they should be marketed promptly after removal from storage. Storage at 4°C is recommended for maximum life of these fruits, since Temples, Orlando tangelos, and tangerines have shown susceptibility to chilling injury at 0° to 1°. They should not be stored for longer than 3 to 4 weeks, because they are subject to decay and loss of flavor (*15, 33, 294, 371*). Tangerines usually can

be stored 1 or 2 weeks at 0° without injury but not longer.

Early harvested specialty citrus often require degreening with ethylene gas for up to 36 hours at 28° to 29°C with 90 to 96 percent relative humidity immediately after harvest (*1008*). Application of a wax coating is also a standard practice to retard moisture loss. Application of an approved benzimidazole fungicide alone or with other approved fungicides is essential before storage or shipping to control decay (*614*). The recommended transit temperature for mandarin-type fruits is 4° (*1007*).

The recommended requirements for commercially storing fresh vegetables are given in table 13, along with other pertinent information. Detailed descriptions of the storage requirements are given in the text.

Artichokes

Globe Artichokes

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

The true artichoke, a member of the thistle family, is known to the trade as the globe artichoke. The edible bud, made up of a cone of short, thick-stemmed bracts, is seldom stored; but for temporary holding a temperature of about 0°C is recommended, with a relative humidity of 95 to 100 percent to prevent wilting or drying. To maintain quality and storage life, the buds should be precooled to below 5° on the day of harvest (*535*). Large artichokes, 90 mm in length and in width will take almost twice as long to hydrocool as small ones about 75 mm in length and width (*789*). Water loss can be minimized by packing the buds in waxed cartons or in cartons lined with perforated film having fifty 6-mm (1/4-in) holes per

Table 13
Recommended temperature and relative humidity, approximate storage life, highest freezing point, water content, and specific heat for fresh vegetables in commercial storage

Commodity	Temperature °C	Temperature °F	Relative humidity (percent)	Approximate storage life	Highest freezing point[1] °C	Highest freezing point[1] °F	Water content (percent)	Specific heat[2] (Btu/lb · °F)
Artichokes, globe	0	32	95-100	2-3 weeks	− 1.1	29.9	83.7	0.87
Artichokes, Jerusalem	− 0.5-0	31-32	90-95	4-5 months	− 2.2	28.0	79.8	.84
Asparagus	0-2	32-35	95-100	2-3 weeks	− .6	30.9	93.0	.94
Beans, dry	4-10	40-50	40-50	6-10 months	—	—	15.0	.32
Beans, green or snap	[3]4-7	40-45	95	7-10 days	− .7	30.7	88.9	.91
Beans, lima	[3]3-5	37-41	95	5-7 days	− .6	31.0	66.5	.73
Bean sprouts	0	32	95-100	7-9 days	—	—	88.8	.91
Beets, bunched	0	32	98-100	10-14 days	− .4	31.3	—	—
Beets, topped	0	32	98-100	4-6 months	− .9	30.3	87.6	.90
Broccoli	0	32	95-100	10-14 days	− .6	30.9	89.9	.92
Brussels sprouts	0	32	95-100	3-5 weeks	− .8	30.5	84.9	.88
Cabbage, early	0	32	98-100	3-6 weeks	− .9	30.4	92.4	.94
Cabbage, late	0	32	98-100	5-6 months	− .9	30.4	92.4	.94
Cabbage, Chinese	0	32	95-100	2-3 months	—	—	95.0	.96
Carrots, bunched	0	32	95-100	2 weeks	—	—	—	—
Carrots, mature	0	32	98-100	7-9 months	− 1.4	29.5	88.2	.91
Carrots, immature	0	32	98-100	4-6 weeks	− 1.4	29.5	88.2	.91
Cassava	0-5	32-41	85-90	1-2 months	—	—	—	—
Cauliflower	0	32	95-98	3-4 weeks	− .8	30.6	91.7	.93
Celeriac	0	32	97-99	6-8 months	− .9	30.3	88.4	.91
Celery	0	32	98-100	2-3 months	− .5	31.1	93.7	.95
Chard	0	32	95-100	10-14 days	—	—	91.1	.93
Chicory, witloof	0	32	95-100	2-4 weeks	—	—	95.1	.96
Collards	0	32	95-100	10-14 days	− .8	30.6	86.9	.90
Corn, sweet	0	32	95-98	5-8 days	− .6	30.9	73.9	.79
Cucumbers	10-13	50-55	95	10-14 days	− .5	31.1	96.1	.97
Eggplants	8-12	46-54	90-95	1 week	− .8	30.6	92.7	.94
Endive and escarole	0	32	95-100	2-3 weeks	− .1	31.9	93.1	.95
Garlic	0	32	65-70	6-7 months	− .8	30.5	61.3	.69
Ginger	13	55	65	6 months	—	—	87.0	.90
Greens, leafy	0	32	95-100	10-14 days	—	—	—	—
Horseradish	− 1.0-0	30-32	98-100	10-12 months	− 1.8	28.7	74.6	.80

Table 13
Recommended temperature and relative humidity, approximate storage life, highest freezing point, water content, and specific heat for fresh vegetables in commercial storage—Continued

Commodity	Temperature		Relative humidity (percent)	Approximate storage life	Highest freezing point[1]		Water content (percent)	Specific heat[2] (Btu/lb · °F)
	°C	°F			°C	°F		
Jicama	13-18	55-65	65-70	1-2 months	—	—	—	—
Kale	0	32	95-100	2-3 weeks	−.5	31.1	86.6	.89
Kohlrabi	0	32	98-100	2-3 months	−1.0	30.2	90.3	.92
Leeks	0	32	95-100	2-3 months	−.7	30.7	85.4	.88
Lettuce	0	32	98-100	2-3 weeks	−.2	31.7	94.8	.96
Melons								
Cantaloup (3/4-slip)	2-5	36-41	95	15 days	−1.2	29.9	92.0	.94
Cantaloup (full-slip)	0-2	32-36	95	5-14 days	−1.2	29.9	92.0	.94
Casaba	10	50	90-95	3 weeks	−1.0	30.1	92.7	.94
Crenshaw	7	45	90-95	2 weeks	−1.0	30.1	92.7	.94
Honey Dew	7	45	90-95	3 weeks	−.9	30.3	92.6	.94
Persian	7	45	90-95	2 weeks	−.8	30.5	92.7	.94
Watermelons	[3]10-15	50-60	90	2-3 weeks	−.4	31.3	92.6	.94
Mushrooms	0	32	95	3-4 days	−.9	30.4	91.1	.93
Okra	7-10	45-50	90-95	7-10 days	−1.8	28.7	89.8	.92
Onion, green	0	32	95-100	3-4 weeks	−.9	30.4	89.4	.91
Onion, dry	0	32	65-70	1-8 months[4]	−.8	30.6	87.5	.90
Onion sets	0	32	65-70	6-8 months	−.8	30.6	87.5	.90
Parsley	0	32	95-100	2-2.5 months	−1.1	30.0	85.1	.88
Parsnips	0	32	98-100	4-6 months	−.9	30.4	78.6	.83
Peas, green	0	32	95-98	1-2 weeks	−.6	30.9	74.3	.79
Peas, southern	4-5	40-41	95	6-8 days	—	—	66.8	.73
Peppers, chili (dry)	0-10	32-50	60-70	6 months	—	—	12.0	.30
Peppers, sweet	7-13	45-55	90-95	2-3 weeks	−.7	30.7	92.4	.94
Potatoes, early crop	([3])		90-95	([3])	−.6	30.9	81.2	.85
Potatoes, late crop	([3])		90-95	5-10 months	−.6	30.9	77.8	.82
Pumpkins	10-13	50-55	50-70	2-3 months	−.8	30.5	90.5	.92
Radishes, spring	0	32	95-100	3-4 weeks	−.7	30.7	94.5	.96
Radishes, winter	0	32	95-100	2-4 months	—	—	—	—
Rhubarb	0	32	95-100	2-4 weeks	−.9	30.3	94.9	.96
Rutabagas	0	32	98-100	4-6 months	−1.1	30.0	89.1	.91
Salsify	0	32	95-98	2-4 months	−1.1	30.0	79.1	.83
Spinach	0	32	95-100	10-14 days	−.3	31.5	92.7	.94
Squashes, summer	5-10	41-50	95	1-2 weeks	−.5	31.1	94.0	.95
Squashes, winter	10	50	[4]50-70	([3])	−.8	30.5	85.1	.88
Sweetpotatoes	[3]13-16	55-60	85-90	4-7 months	−1.3	29.7	68.5	.75
Tamarillos	3-4	37-40	85-95	10 weeks	—	—	—	—
Taro (Dasheen)	7-10	45-50	85-90	4-5 months	—	—	73.0	.78
Tomatoes, mature-green	[3]13-21	55-70	90-95	1-3 weeks	−.6	31.0	93.0	.94
Tomatoes, firm-ripe	[3]8-10	46-50	90-95	4-7 days	−.5	31.1	94.1	.95
Turnips	0	32	95	4-5 months	−1.0	30.1	91.5	.93
Turnip greens	0	32	95-100	10-14 days	−.2	31.7	90.3	.92
Waterchestnuts	0-2	32-36	98-100	1-2 months	—	—	78.3	.83
Watercress	0	32	95-100	2-3 weeks	−.3	31.4	93.3	.95
Yams	16	61	70-80	6-7 months	—	—	73.5	.79

[1] Data from Whiteman (*1030*).
[2] Specific heat calculated from Siebel's (*838*) formula: S = 0.008 × (percent water in food) + 0.20. In metric units of kJ/kg/°C, S = 0.0335 × (percent water in food) + 0.8374.
[3] See text.
[4] See text for cultivar differences.

1,000 cm² (ft²). The holes are necessary to drain excess water from hydrocooling and to release heat and gas produced from respiration. Artichokes of good quality without decay or freezing injury will keep in good condition for 2 to 3 weeks at 0° (*751*).

Jerusalem-Artichokes (Girasole)
(Temperature, −0.5° to 0°C (31° to 32°F); relative humidity, 90 to 95 percent)

Jerusalem-artichokes, which are not true artichokes, but tubers, can be stored 4 to 5 months if held at a temperature of −0.5° to 0°C and high relative humidity. At low humidities they shrivel badly and are more likely to decay than if kept in a moist atmosphere. Their thin skin is easily injured and allows moisture to be lost readily, causing shriveling (*946*). If stored 5 months, losses due to decay and shrivel may amount to 20 percent (*958*).

Asparagus

(Temperature, 0° to 2.0°C (32° to 36°F); relative humidity, 95 to 100 percent)

Fresh asparagus is highly perishable and deteriorates rapidly at temperatures above 5°C (fig. 6). Thus, the spears should be cooled immediately after cutting, preferably by hydrocooling, and placed at a low temperature. In addition to general deterioration, growth, loss of tenderness, loss of flavor, loss of vitamin C, and development of decay take place at moderately high temperatures. Asparagus can be kept successfully for about 3 weeks at 2°. It can be held for about 10 days at 0°, but it is subject to chilling injury when held longer at this temperature.

High relative humidity is essential to prevent desiccation, particularly at the butt ends. Commonly, the desired relative humidity is obtained by placing the butts of asparagus on wet pads. A high relative humidity can also be obtained by prepackaging spears in perforated film. Nonperforated film is not acceptable because the extent of increase in carbon dioxide and decrease in oxygen may be injurious and because enough ethylene may accumulate to toughen the spears (*309*).

Asparagus with white butts is less perishable than all-green asparagus. Bacterial soft rot, which can occur at either the tip or butt of the asparagus, is the principal decay (*851*).

Controlled-atmosphere storage is beneficial to asparagus even for a short period because it retards decay and toughening, which occur rapidly after harvest (*523, 546*). If temperature control is uncertain and might exceed 5°C, the carbon dioxide concentration should not exceed 7 percent; but if the temperature is maintained at 0°, a 12 percent concentration is suggested. Brief exposure to 20 percent carbon dioxide will reduce soft rot at the butt end (*520*).

(See also *517, 518, 789*.)

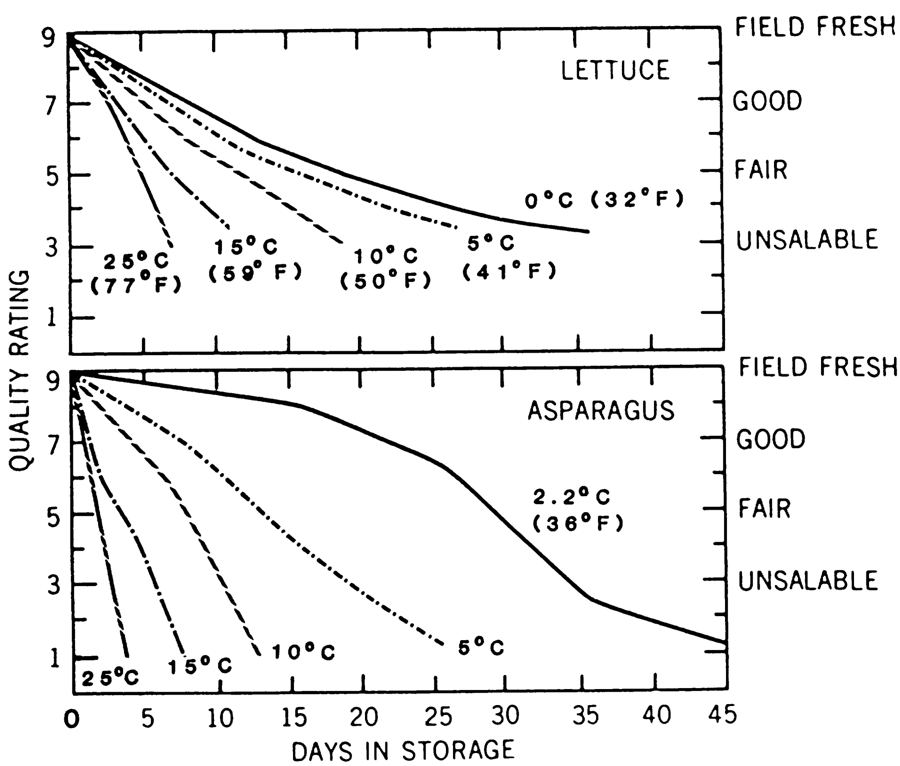

Figure 6
Quality ratings of asparagus and untrimmed lettuce stored at five temperatures. (Lettuce data adapted from Morris, Pratt, and Tucker (*648*) and asparagus data from Lipton (*517*).)

Beans

Green, or Snap, Beans
(Temperature, 4° to 7°C (40° to 45°F); relative humidity, 95 percent)

Green beans should be stored only for a short period—between 7 to 10 days at the recommended temperatures of from 4° to 7°C. Even these temperatures cause some chilling but are best for short storage (*283, 1011*). Snap beans are cold sensitive and may be severely chilled in a few days at temperatures of 3° and below. Chilled beans develop surface pitting and russeting a day or two after removal to warm temperatures for marketing (*851, 1011*). Tendergreen beans can be held for about 2 days at 0.5°, 4 days at 2.5°, or 12 days at 5° before chilling injury is induced. However, cultivars differ significantly in their sensitivity to chilling (*283, 1012*).

Russeting is aggravated by free moisture and is especially noticeable in the centers of containers, where condensed moisture remains.

Beans should not be top iced if they are to be held at higher temperatures later. Snap beans are highly perishable and should be cooled rapidly after harvest, preferably to 4 to 5°C. They can be effectively vacuum cooled or forced-air cooled, but hydrocooling is preferable not only because cold water cools rapidly but also because the free moisture helps prevent wilting or shriveling (*283, 789*). Snap beans lose moisture rapidly if not properly protected by packaging or by a relative humidity of 95 percent or above. When the relative humidity approaches saturation, as in consumer packages, temperatures above 7° must be avoided or decay is likely to be serious within a few days (*945*).

Beans can be held about 10 days at 4°C if they are utilized immediately after storage, as for processing. Longer storage or holding at temperatures above 7° will hasten yellowing and the development of fiber (*538, 1011*).

Containers of beans should be stacked to allow abundant air circulation. If containers are packed close together, the temperature may rise because of the heat of respiration, and the beans will deteriorate rapidly. When beans are stored in large bins or pallet boxes, provision should be made for rapid cooling. Beans stored too long or at too high a storage temperature are subject to various decays, including watery soft rot (*Sclerotinia* spp.), cottony leak (*Pythium butleri*), gray mold (*Botrytis cinerea*), and rhizopus rot (*Rhizopus* spp.) (*851*).

Beans principally benefit from use of a controlled atmosphere (2 to 3 percent oxygen and 5 to 10 percent carbon dioxide) because it retards yellowing (*300*). Also, the discoloration of broken ends of beans awaiting processing can be controlled by holding them in 20 or 30 percent carbon dioxide for 24 hours (*387*). (See also *842*.)

Lima Beans
(Temperature, 3° to 5°C (37° to 41°F); relative humidity, 95 percent)

Lima beans are highly perishable and also sensitive to chilling injury, so they are precooled, preferably by hydrocooling, immediately after harvest and kept at a low temperature (*459*). Pods are more sensitive to chilling injury than the beans, so the unshelled beans should be kept at 5° to 6°C. Shelled beans can be kept at 3° to 4°. At these temperatures, the loss in quality resulting from the combination of normal deterioration and chilling injury is less than that due to either normal deterioration at higher temperatures or chilling injury at lower temperatures. Injury and deterioration of pods are indicated by rusty-brown specks and spots which increase sharply at 21°, and shelled lima beans become spotty and sticky (*118, 607*). Unshelled lima beans can be kept for about 5 days and shelled beans for about a week at the respective suggested temperatures.

Shelled lima beans are sometimes stored in perforated polyethylene bags. An atmosphere of high carbon dioxide content is desirable. For example, one with 25 to 30 percent carbon dioxide reduces stickiness and spotting of seeds by inhibiting fungal and bacterial growths. The effect of a low-oxygen atmosphere has not been reported.

Dry Beans
(Temperature, 4° to 10°C (40° to 50°F); relative humidity, 40 to 50 percent)

Properly cured, cleaned, and dried beans are well adapted to storage. Storage at low temperatures ranging from 4° to 10°C helps materially in preserving both seed and culinary quality. A desirable temperature for storage during the winter months is approximately 4°. If beans are to be moved from storage early in the winter, cooling the beans to 7° to 10° is sufficient (*562*). Since dry beans tend to split more easily when cold, there is no advantage in cooling them below a temperature suitable to maintain quality. Storage for 6 to 10 months is possible at 4°. Dry pinto beans are often stored at ambient temperature and 50 to 70 percent relative humidity. If the beans have a moisture content below 14 percent, it is prudent to store them at 70 percent relative humidity to avoid seedcoat cracking.

Navy (pea) beans are best harvested and handled when their moisture content is from 16 to 20 percent, with perhaps 17 to 18 percent being optimum. Low-moisture beans (11 to 12 percent) are much more susceptible to mechanical damage than those at 18 percent (*562*). Beans with above 18 percent moisture should be checked frequently and removed from farm storages as soon as possible. Storage elevators are equipped to provide heat and ventilation for drying high-moisture beans. Dry beans can be stored on the farm in wood, concrete, or steel bins. An aeration system is essential to provide airflow rates high enough to cool all the beans in a bin. A minimum airflow of 0.14 m^3 (5 ft^3)/minute/bushel should be provided to dry beans with unheated air (*562*). Aeration also reduces mold growth since mold activity decreases rapidly at temperatures below 20°C. Most molds are inactive at 10° and below. With storage at 10° and about 50 percent relative humidity, there should be little if any weevil infestation and the beans should neither lose nor gain weight.

Storage at high humidities (75 to 80 percent) and high temperatures (24 to 38°C) caused undesirable darkening of white pea beans (*209*) and light red kidney beans (*421*). Light red kidney beans stored at 1°C and 30 percent relative humidity for 1 year retained their original color and cooking time requirements (*421*).

Bean Sprouts

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Mung bean plants are classified as being chilling sensitive; however, the sprouts are highly perishable and store best at 0°C and 95 to 100 percent relative humidity. The respiration rate of mung bean sprouts is high, and the rate increases sharply with temperature, as noted for several other crops with relatively high rates of carbon dioxide produc-

tion (*528*). The shelf life decreases sharply with increases in holding temperature. Symptoms of deterioration are darkening of radicle and cotyledons, development of dark streaks on the hypocotyl, and eventual development of sliminess, decay, and a musty odor. The sprouts remain in good salable condition at 0° for 7 to 9 days (*528, 938*). Shelf life of sprouts kept at 0° but exposed daily to 20° for 30 minutes can be reduced by 50 percent, which emphasizes the importance of immediate cooling and holding at 0°. At 2.5°, 5°, and 10°, the maximum salable life is 5.5, 4.5, and 2.5 days, respectively (*528*). Perforated film packaging has been reported to be helpful in maintaining the quality of sprouts of mung beans, soybeans, and azuki beans (*937*).

Beets

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

Like other root crops, beets are well adapted to storage. Topped beets stored at 0°C can be expected to keep 4 to 6 months under suitable storage conditions. Either cold storage or cool-cellar storage is suitable, provided the humidity is kept sufficiently high to prevent shriveling. Cellar storage temperatures fluctuate and are often higher than 0°, so the period of successful storage will be comparatively shorter. The temperature in such storages should not exceed 7° to minimize sprouting and decay. Beets wilt readily from loss of water; therefore, they should be kept where the humidity is sufficiently high to prevent excessive evaporation (*389, 959*). Small beets soften and shrivel earlier than larger ones.

Before beets are stored, they should be topped and sorted to remove all those with disease or mechanical injury. Beets should not be stored in large bulk; and they should be stored in well-ventilated containers, such as ventilated bin boxes or slatted crates, to help dissipate respiratory heat. Increasing the carbon dioxide level in beet storages to 5 to 10 percent increased fungal spoilage (*982*).

Bunched beets are much more perishable than topped beets, but they can be stored at 0°C for 10 days to 2 weeks. Use of crushed ice is helpful in keeping the bunched beets cold, especially if refrigeration is not available. See also *862*.

Broccoli (Italian, or Sprouting)

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Italian, or sprouting, broccoli is highly perishable, and it is usually stored for only a brief period as needed for orderly marketing. Broccoli should be hydrocooled or packed in ice immediately after harvest and kept at 0°C to maintain good salable condition, fresh green color, and vitamin C content. If in good condition and stored with adequate air circulation and spacing between containers to avoid heating, broccoli should keep satisfactorily 10 to 14 days at 0°. Longer storage is undesirable because leaves discolor, buds may yellow and drop off, and tissues soften (*640, 856*). The respiration rate of freshly harvested broccoli is very high—comparable to that of asparagus, spinach, or sweet corn. Thus, like these crops, broccoli must be cooled immediately after harvest to rapidly lower the respiration rate and be kept at low temperature for maximum shelf life (*750*).

A controlled atmosphere of 10 percent carbon dioxide and/or 1 percent oxygen can increase the shelf life of good quality broccoli held above 5°C. An atmosphere with 10 percent carbon dioxide retards yellowing and toughening, and one with 15 percent carbon dioxide has the same retarding effect but can induce persistent off-odors. A 1-percent-oxygen atmosphere retards yellowing but one with 0.1 to 0.25 percent oxygen can cause severe injury and result in off-odors and off-flavors in cooked broccoli (*457, 530*). Film wraps can be beneficial in maintaining high relative humidity and extending the storage life (*800*). They should be perforated or be sufficiently permeable, however; otherwise, an atmosphere that causes injury and/or off-odors, particularly at 0°, may develop within the wraps (*457*). Broccoli should not be stored with fruits, such as apples or pears, that produce substantial quantities of ethylene, because this gas accelerates yellowing of the buds. (See also *789*.)

Brussels Sprouts

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Brussels sprouts can be kept in good condition for a maximum of 3 to 5 weeks at 0°C (*558, 720*). Longer storage may result in black specking of the leaves, loss of fresh bright-green color, decay, wilting, and discoloration of the cut stems. Rate of deterioration is twice as fast at 5° as at 0°. At 10° and above, deterioration—yellowing of the sprouts and discoloration of the stem end—is rapid; yellowing becomes evident within 1 week at 10° (*720*).

A controlled atmosphere (CA) of 2.5 to 5 percent oxygen and 5 to 7.5 percent carbon dioxide is helpful to the quality maintenance of brussels sprouts held at 5° or 10° but not at 0° (*227, 559*). Oxygen levels below 1 percent can cause internal discoloration (*227, 559*). CA extends storage about a week at 5°. Film packaging or film crate liners are useful in preventing moisture loss because transpiration by brussels sprouts is high even if the relative humidity is kept at the recommended level (*801, 920*). The film should be perforated because accumulated volatiles other than carbon dioxide produced by the brussels sprouts result in objectionable odor or flavor and because a buildup of 20 percent carbon dioxide in the atmosphere can cause injury. As with broccoli, sufficient air circulation and spacing between packages are desirable to allow good cooling and to prevent yellowing and decay (*801, 920*). Also, brussels sprouts should not be stored with fruits because ethylene from the fruits will accelerate yellowing and can cause abscission of leaves.

Cabbages

Common Cabbage

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

A large percentage of the late crop of cabbage is stored and sold during the winter and early spring, or until the new crop from the Southern States appears on the market. If stored under proper conditions late cabbage should keep for 5 to 6 months. The longest keeping cultivars belong to the Danish class. Early-crop cabbage, especially southern grown, has a storage life of 3 to 6 weeks.

Cabbage is successfully held in common storage in the Northern States, where a fairly uniform inside air temperature of 0° to 1.5°C can be maintained. Many such storage houses are to be found, principally in New York, Pennsylvania, Michigan, and Wisconsin.

Storage houses should be insulated sufficiently to prevent freezing of the cabbage; for although slight freezing does little harm, hard freezing may cause considerable loss. Heaters are sometimes needed to prevent freezing of cabbage in common storage during severe cold weather.

Cabbage wilts quickly if held under too dry storage conditions; hence, the humidity should be high enough to keep the leaves fresh and turgid. Use of polyethylene liners or pallet covers to prevent desiccation can prove desirable under some storage conditions (*696*). Cabbage stored at 0°C has less decay when the relative humidity is maintained at or near saturation (98 to 100 percent) than at 90 to 95 percent (*704, 981*).

Many growers now use pallet boxes as both field and storage containers so that there is no handling of the cabbage from the time of harvest until preparation for shipment or processing. Some of the larger storages stack these pallet boxes five high.

An increasing quantity of cabbage is now held in mechanically refrigerated storages. The storage life of late cabbage can be extended for several months (*433*) if it is held in an atmosphere with 2.5 to 5 percent oxygen and 2.5 to 5 percent carbon dioxide. (See also *266, 394.*)

Cabbage should be handled carefully from field to storage, and only solid heads with no yellowing, decay, or mechanical injuries should be stored. Before the heads are stored, all loose leaves should be trimmed away; only three to six tight wrapper leaves should be left on the head. Loose leaves interfere with ventilation between heads, and ventilation is essential for successful storage. Upon removal from storage, the heads should be trimmed again to remove loose and damaged leaves. Cabbage should not be stored with fruits emitting ethylene. Concentrations of 10 to 100 p/m of ethylene cause leaf abscission and loss of green color within 5 weeks.

The most common decays found in stored cabbage are watery soft rot, bacterial soft rot, gray mold rot, alternaria leaf spot, and black leaf speck (*749*).

Chinese Cabbage

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Chinese cabbage can be stored 2 to 3 months at 0°C (32°F) with 95 to 100 percent relative humidity (*997*). Considerable losses are expected after 3 or 4 months of storage at 0° (*332, 997, 1019*). Storage life is shorter at higher temperatures. A low concentration (1 percent) of oxygen was reported to be beneficial in extending the storage life of Chinese cabbage (*997*).

Outer diseased or injured leaves should be removed before the heads are stored. The heads should be packed loosely, and preferably upright, in crates. Spacing in storage should allow for air circulation.

Carrots

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

Mature carrots are well adapted for storage and are stored in large quantities during the fall and winter for both the fresh market and processing. Careful handling during and after harvest to avoid bruising, cutting, and breakage will help ensure successful storage.

Mature topped carrots can be stored 7 to 9 months at 0° to 1°C with a very high relative humidity, 98 to 100 percent (*485, 976, 979*). However, even under these optimum conditions 10 to 20 percent of the carrots may show some decay after 7 months. Under commonly found commercial conditions (0° to 5°) with 90 to 95 percent relative humidity, 5 to 6 months' storage is a more realistic expectation (*789*). Prompt cooling to 5° or below after harvest is essential for extended storage. Poorly precooled roots decay more rapidly.

Carrots lose moisture readily and wilting results. Humidity should be kept high. Carrots stored at 98 to 100 percent relative humidity develop less decay, lose less moisture, and remain crisper than those stored at 90 to 95 percent relative humidity (*480, 485, 979, 980*). A temperature of 0° to 1°C is essential if decay and sprouting are to be minimized. With storage at 5° to 10°, considerable decay and sprouting may develop within 1 to 3 months (*485, 722, 832*).

Prestorage washing of carrots may be desirable if they are harvested under wet conditions. Many potential decay-causing organisms are removed by washing. Also, clean, washed carrots allow freer air circulation. Air circulation between crates or pallet boxes in which carrots are stored is desirable to remove respiratory heat, maintain uniform temperatures, and help prevent condensation. An air velocity of about 7 to 10 cm/second (14 to 20 ft/min) is adequate at low storage temperatures (*976*).

Carrots for processing may be given a prestorage dip treatment in a 0.1-percent solution of sodium *o*-phenylphenate (SOPP) to effectively reduce storage decay (*1024*). The solution is not rinsed off after treatment.

The storage life of immature **bunched carrots** is limited by the high perishability of the tops. They should keep 2 weeks at 0°C with 95 to 100 percent relative humidity. Contact ice is recommended to maintain freshness.

Most carrots for the fresh market are not fully mature. These **immature or partially mature carrots** are topped and packed in polyethylene consumer bags or 23-kg (50-lb) mesh bags for marketing. If precooled promptly before packaging and trimmed of all traces of leaf growth, they can be held 4 to 6 weeks at 0°C, with 98 to 100 percent relative humidity recommended. Film bags for carrots should be perforated to allow ventilation and prevent development of off-odors or off-flavors. Twelve 3-mm holes for 1-kg bags (six 1/8-in holes for 1-lb bags) are suggested for ventilation (*343*).

Immature, topped carrots may be hydrocooled or packed in crushed ice for cooling. Loose carrots can be hydrocooled from 25° to 5°C in about 9 minutes if the water is 1°. If the carrots are in 23-kg (50-lb) mesh bags, the same degree of cooling requires about 11 minutes (*789*). Sometimes top ice is used with bagged, precooled carrots. The top ice provides some of the necessary refrigeration and prevents dehydration.

Bitterness in carrots, which may develop in storage, is due to abnormal metabolism caused by ethylene. This gas is given off by apples, pears, and certain other fruits and vegetables and from decaying tissues. Bitterness can be prevented by storing carrots away from such products (*140*). Also, development of bitterness can largely be avoided by low-temperature storage, as it minimizes ethylene production. Some surface browning or oxidative discoloration often develops in stored carrots. The most immature carrots are the most susceptible to surface browning (*155*).

The highest freezing point for carrots is −1.2°C. Severe injury in carrots immediately after freezing is identified by lengthwise cracking and by blistering caused by the formation of ice crystals immediately beneath the surface. After thawing, a darkened (dark brown or black) and watersoaked skin is observed (*693*), and the carrots are soft and flabby.

Use of controlled atmospheres to extend storage of carrots has not been promising. Atmospheres containing 5 to 10 percent carbon dioxide with reduced oxygen concentrations (2.5 to 6 percent) caused a marked increase in mold growth and rotting over that of carrots stored in air (*976, 1018*). (See also *1046*.)

The most important decays of carrots in storage are gray mold rot (*Botrytis*), watery soft rot (*Sclerotinia*), crater rot (*Rhizoctonia*), fusarium rot, rhizopus soft rot, bacterial soft rot, black rot (*Stemphylium*), and sour rot (*Geotrichum*). Spoilage losses will be minimized if the following precautions are observed: Use new or disinfested storage containers, handle carefully to prevent injuries, precool carrots, maintain them at a temperature near 0°C, and avoid temperature fluctuations. For further information on diseases see *744, 832, 851*.

Cassava

(Temperature, 0° to 5°C (32° to 41°F); relative humidity, 85 to 90 percent)

In most cassava producing areas, the roots are normally left in the ground until needed (*426*). Although they can be harvested over a long period, the older roots tend to become fibrous and woody (*102*). In areas where refrigeration is not available or not economical, it is a common practice to rebury the harvested roots in a cool place for short storage. Simple field structures or packing in moist materials, such as sawdust, in wooden boxes allows curing and storage of fresh cassava roots for 1 to 2 months (*102*). Packaging with polyethylene bags can also be helpful to keep cassava fresh at ambient temperatures (*687*). (See also *759*.)

Studies have shown that cassava can be kept well at 0° to 5°C with 85 to 90 percent relative humidity (*426*). Varietal differences, climatic conditions, and mechanical damage during harvesting all affect the deterioration process and storage capacity of cassava roots.

Fresh cassava roots are easily bruised and, when bruised, turn grayish. Therefore, careful handling is necessary. Internal discoloration, particularly vascular streaking, is also a serious problem that occurs during storage (*57, 572*).

Cassava can also be stored in dehydrated form. In this case, roots are washed, peeled, sliced or chipped, and dried in the sun or in the oven until the moisture content decreases from 60 to 70 percent down to 10 to 14 percent (*774*). When adequately dried, cassava will usually keep for 3 to 6 months unless insect infestation becomes excessive (*426*).

Cauliflower

(Temperature, 0°C (32°F); relative humidity, 95+ percent)

Cauliflower is not usually kept in cold storage in the United States; however, an oversupply can be stored for a short time to await a more favorable market. If in good condition, cauliflower can be held satisfactorily for 3 to 4 weeks at 0°C (*390, 722, 855*). The storage life is about 2 weeks at 3°, 7 to 10 days at 5°, 5 days at 10°, and 3 days at 15° (*390*). Slightly immature, compact heads keep better than more mature ones. Successful cold storage depends not only on preventing decay, spotting, and watersoaking but also on retarding aging (browning and riciness) of the head, or curd, and in preventing the leaves from wilting, yellowing, and dropping off. A high relative humidity of at least 95 percent is desirable to prevent wilting. Canadian researchers found that a humidity of 98 to 100 percent was satisfactory for cauliflower, mainly because it allowed even less weight loss to occur than that at 90 to 95 percent (*980*). Containers should be handled carefully to avoid bruising of the heads; they should be stacked with the flower heads down to protect the curds from bruising and from dirt. Slatted crates or bins should be used so that moderate air circulation can remove the heat of respiration. When it is desirable to hold cauliflower temporarily out of cold storage, packing in crushed ice will aid in keeping it fresh. Freezing causes a grayish-brown discoloration and softening of the curd accompanied by a water-soaked condi-

tion. After freezing, affected tissues may be rapidly invaded by soft-rot bacteria.

Precooling after harvest is very beneficial. Both vacuum cooling and hydrocooling are practical methods of lowering the product temperature to 5°C or below. Trimmed cauliflower can be hydrocooled from 21° to 5° in about 20 minutes in 1° water. Film-wrapped cauliflower can be vacuum cooled to obtain a similar temperature drop in 30 minutes if prewetted (*918*).

Much of the cauliflower now marketed is closely trimmed of leaves, prepackaged in perforated film overwraps, and packed in fiberboard containers. The overwraps should have four to six 5-mm (1/4-in) holes to allow adequate ventilation.

In general, use of various controlled atmospheres has not been promising. The storage life of cauliflower was not extended by either low oxygen or high carbon dioxide at 2.5°, 5°, or 7.5°C, and cauliflower curds were injured by low oxygen (2 percent or less) or by high carbon dioxide (5 percent or more). Injury due to controlled atmospheres is mainly apparent only when the stored product is cooked (*531, 532*). (See also *8*.)

Celeriac

(Temperature, 0°C (32°F); relative humidity, 97 to 99 percent)

Celeriac or celery root should be stored under the same conditions as those for topped carrots, and it should keep 6 to 8 months with only minor losses at 0°C if the relative humidity is 97 to 99 percent. If storage is above 1°, the relative humidity should be about 95 percent, or decay losses will be substantial within 6 months (*485*). The storage life is only about 4 months at 4° to 5° if losses are to be held below 15 percent. Celeriac can be held in common storage in cool climates a maximum of 4 to 5 months if temperatures do not exceed 3° (*1034*). The use of slatted crates or bins with a moderate amount of air circulation provides the conditions needed to remove the heat of respiration.

Controlled atmospheres have not been advantageous for cultivars tested. Low oxygen atmospheres have not reduced losses, and high carbon dioxide (5 to 7 percent) increased decay during 5 months of storage (*1016, 1017*).

Celery

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

Celery should keep for 2 to 3 months if stored in rooms held uniformly at 0°C. However, less celery is stored now than in former years. Since wilting is a major cause of deterioration, it is best to store celery at a very high relative humidity (98 to 100 percent) and with sufficient air circulation to keep temperatures at the top and bottom of the room as nearly equal as possible (*503, 690, 696, 975*). Spreading burlap on the storage room floor and keeping it constantly wet is one method of maintaining a high relative humidity. The use of perforated polyethylene film crate or carton liners also provides an effective method of maintaining high relative humidity to minimize moisture loss (*690, 696*). Prepackaging with shrink-film sleeves or with open-top plastic bags also is a good way to retain moisture without the danger of accumulating carbon dioxide or depleting oxygen.

Celery can be precooled by refrigerated forced-air cooling, by hydrocooling, or by vacuum cooling (*919, 922*). Hydrocooling is the most common precooling method, and temperatures should be brought as near to 0°C as possible. In practice, temperature reduction is often only to 4.5° to 7°. Vacuum cooling is widely used for celery packed in corrugated cartons for long-distance shipment. Ice is often added to the crates to keep the celery near 0°.

Air circulation can be maintained around crates by using dunnage strips between the crates and leaving air channels between rows. If wall or ceiling refrigerating coils are used, fans should be located so that they will provide adequate air circulation. Celery should not be stacked more than four crates high in storages without forced-air circulation; otherwise, there is danger of overheating due to heat of respiration.

For better storage, celery should be cut with a small piece of root attached and harvested before the outer stalks become pithy. Some growth takes place in celery while in storage; the central stalks lengthen considerably. Some blanching of the stalks also takes place in most cultivars during storage. Celery is rather perishable, and under unsuitable storage conditions it is especially subject to watery soft rot. This disease originates in the field and is caused by a fungus that is able to develop to some extent even at 0° to 2°C (*851*).

Use of the jacketed-room system for cold storage has proven successful for celery in Canadian tests. Weight losses at 0°C averaged 1.25 percent/month in jacketed storage as compared with 2.5 percent/month in directly cooled rooms (*503*).

An atmosphere containing 3 percent oxygen and 5 percent carbon dioxide reduced decay and loss of green color in celery held at 0°C in high-humidity storage (*975*).

Chicory (Witloof or Belgian Endive)

(Temperature, 0°C (32°F); relative humidity, 95 percent)

This bullet-shaped salad vegetable should keep 2 to 4 weeks at 0° to 2°C with high relative humidity. Compact heads 10 to 13 cm (4 to 5 in) in length are most desired. This vegetable is mainly imported by air from Europe. Overwrapping with perforated plastic film is beneficial. In marketing, blue paraffin paper may be used for protection against light and moisture loss. Leaves should be white with slightly yellow tips. Deterioration shows as marginal leaf browning after 2 to 4 weeks at 2°, 1 to 2 weeks at 5°, and 1 week at 15° (*391*). Holding witloof chicory in 3 to 4 percent oxygen with 4 to 5 percent carbon dioxide at 0° about doubles its useful life compared to

storage in air. This controlled atmosphere delays greening of the tips of the leaves in light and opening of the heads.

Corn, Sweet

(Temperature, 0°C (32°F); relative humidity, 95 to 98 percent)

Sweet corn is seldom stored, although occasionally it may be desirable to store an excess supply temporarily. However, storage for more than a few days results in serious deterioration and loss of tenderness and sweetness. The sugar content, which so largely determines quality in corn and which decreases rapidly at ordinary temperatures, decreases less rapidly if the corn is kept at about 0°C (fig. 7). The loss of sugar is about four times as rapid at 10° as at 0° (*51*). At 30°, 60 percent of the sugars may be converted to starch in a single day as compared with only 6 percent at 0°. However, corn loses sweetness or desirable flavor fairly rapidly, even when iced and held at 0° (*841, 917*). Long shanks and flag leaves should be trimmed before marketing, as they induce denting of the kernels by drawing moisture from them (*836*). Denting is an indication of loss of quality. A loss of 2 percent moisture from sweet corn

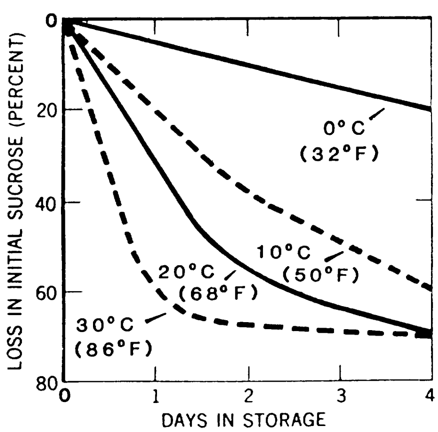

Figure 7
Sucrose depletion in sweet corn at four temperatures. Adapted from Appleman and Arthur (*51*).

may result in objectionable kernel denting.

Rapid removal of field heat from sweet corn, often at 30°C (86°F) or higher, is especially critical to retard deterioration. Maximum quality retention can be obtained by precooling corn to near 0° within an hour after harvest and holding ears at 0° during marketing. In practice cooling to this extent is rarely achieved. However, cooling is the first step in a good temperature management program. Sweet corn has a high respiration rate, which results in a high rate of heat evolution. Sweet corn can be precooled adequately by vacuum cooling, but it must be wetted first (and top iced after vacuum cooling) (*31, 834, 917*). Crated corn can be vacuum cooled from about 30° to 5° in a half hour. Hydrocooling by spraying, showering, or immersion in water at 0° to 3° is effective, although it takes longer than vacuum cooling for the same temperature reduction if the corn is packed before it is cooled. Crated corn would take over an hour in a hydrocooler to cool to 5°, and few, if any, operators leave it that long. It is important to check cob temperatures during hydrocooling to determine if temperatures are being lowered to at least 10°. Hydrocooling nomographs for bulk and crated sweet corn are described in reference *922*. Many hydrocoolers now handle palletized crates, with crates four or five layers high. These coolers, with overhead spray nozzles, can be effective if they use a large volume of water and allow an hour or more of operation (*31, 78, 299*). After hydrocooling, top icing is desirable during transport or holding to hasten continued cooling, remove the heat of respiration, and keep the husks fresh. When precooling facilities are not available, corn can be cooled with package ice and top ice.

Sweet corn should not be handled in bulk unless copiously iced, because it tends to heat throughout the pile. Corn should not be expected to keep in marketable condition even in cold storage at 0°C for more than 5 to 8 days. The storage life at 5° is about 3 to 5 days and at 10° about 2 days.

Some corn is prepackaged in moisture-retentive film, with the husks removed after precooling. The film should be perforated to prevent development of off-odors or off-flavors. This product is very perishable and must be marketed with continuous refrigeration (*333*).

Use of controlled atmospheres to extend storage offers little promise. Research has shown that injurious atmospheres contain less than 2 percent oxygen or more than 20 percent carbon dioxide (*645, 896*). In an atmosphere with 2 percent oxygen, the sucrose content of sweet corn remained higher than in other atmospheres tested (*896*). Some of the new, high-sugar sweet corn cultivars should improve consumer satisfaction. As compared with standard cultivars, which contain 3 to 5 percent sugar at harvest, the new cultivars contain 7 to 10 percent sugar and also lose their sweetness more slowly during marketing. Thus, consumers purchasing the sweeter cultivars after several days' storage should get corn with 5 to 6 percent sugar as compared with standard cultivars containing only 2 to 3 percent sugar after similar postharvest handling.

Cucumbers

(Temperature, 10° to 13°C (50° to 55°F); relative humidity, 95 percent)

Cucumbers can be held 10 to 14 days at 10° to 13°C with high relative humidity. They are subject to chilling injury if held longer than about 2 days at temperatures below 10°. At temperatures of 10° and above, they ripen rather rapidly, the green color changing to yellow. This color change starts in about 10 days at 10° and is accelerated if the cucumbers are stored in the same room with apples, tomatoes, or other ethylene-producing crops (*48, 646*) (see p. 28). Modified atmospheres, particularly with low oxygen (5 percent), will retard yellowing (*48*).

Cucumbers are very susceptible to shriveling; hence, the humidity in

the storage should be kept high. Cucumbers for the fresh market are usually waxed to reduce moisture loss (*355*). Shrink-wrapping with polythylene film can also delay the loss of turgidity (*399*).

Symptoms of chilling injury are water-soaked spots, pitting, or tissue collapse. A surge in ethylene production may occur (*998*) and extensive decay will develop (*647*) when chilled cucumbers are removed from low-temperature storage.

Pickling cucumbers have been successfully hydrocooled under experimental conditions and then held 4 days at 4.5°C. They should be utilized immediately after removal from cold storage (*242*).

(See also *225, 258, 749.*)

Eggplants

(Temperature, 8° to 12°C (46° to 54°F); relative humidity, 90 to 95 percent)

Eggplant fruit are chilling sensitive at 10°C and below and deteriorate rapidly at warm temperatures, so they are not adapted to long storage. Pitting, surface bronzing, and browning of seeds and pulp are symptoms of chilling injury, and loss of sheen and wilting are symptoms of normal deterioration. Sensitivity of eggplants to chilling differs with cultivar, maturity, size of fruit, and season of harvest (*4, 5, 961, 1009*). Fruit harvested at optimum maturity or in midsummer are more sensitive than those harvested at an overmature stage or in the fall, when the growing temperature is cool. Thus, eggplants harvested in midsummer can be held about a week at 12°C, whereas those harvested in fall can be held about 10 days at 8° (*789*). Exposure to ethylene for 2 or more days hastens deterioration.

Wrapping eggplants with shrink film reduces weight loss and maintains firmness, due to the high relative humidity. However, wrapped eggplants decay rapidly if the film is not perforated (*764*). Shrink-film-wrapped eggplants are susceptible to decay caused by *Botrytis cinerea* Fr. and *Phomopsis vexans* (Sacc. & Syd.) Hartez (*764*), whereas chilled eggplants are susceptible to decay by *Alternaria* when removed from chilling temperature (*605*).

See *606* for a discussion of diseases of eggplants.

Endive and Escarole

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Endive and escarole are leafy salad greens not adapted to long storage. Even at 0°C, which is considered to be the best storage temperature, they cannot be expected to keep satisfactorily for more than 2 or 3 weeks. Vacuum cooling or hydrocooling can help maintain their fresh appearance. They should keep somewhat longer if stored with cracked ice in or around the packages. The relative humidity in rooms where endive or escarole is held should be kept above 95 percent to prevent wilting.

Garlic, Dry

(Temperature, 0°C (32°F); relative humidity, 65 to 70 percent)

Garlic cloves are best stored under the temperature and humidity conditions required for onions. If in good condition and well cured when stored, garlic should keep for 6 to 7 months at 0°C. Garlic cloves sprout most rapidly at 4° to 18°; hence, prolonged storage at this temperature range should be avoided (*571*). Relative humidity should be lower than for most vegetables because high humidity causes root and mold growth. In California, where considerable garlic is grown, it is frequently put in common storage, where it can be held for 3 to 4 months or sometimes longer if the building can be kept cool, dry, and well ventilated. It is essential that garlic destined for storage be well cured in the field and be provided with adequate air circulation through the storage containers to remove transpired moisture. Incomplete curing results in excessive decay, particularly when bulbs are held above 0°.

Garlic can be held at 27° to 32°C satisfactorily for 1 month or less if the humidity is as low as recommended. Storage life of garlic can be extended by treatment with maleic hydrazide before harvest (*231, 686*) or gamma irradiation after harvest (*231*). These treatments are effective in controlling sprout growth and weight loss and in decreasing external discoloration and diseases. (See also *570, 851.*)

Ginger

(Temperature, 13°C (55°F); relative humidity, 65 percent)

Ginger rhizomes can be safely held for 6 months at 13°C and 65 percent relative humidity. Weight loss under these conditions will be about 16 percent, but this loss is not considered critical. Higher relative humidities are conducive to mold growth (*12*). The rhizomes must be protected from chilling injury and from sprouting during storage. Both dangers are avoided at 13°C. Peeling of skin, shriveling, softening, and purple discoloration of the surface are undesirable. At room temperature, shriveling and sprouting limit storage to about 1 month, whether relative humidity is 35 or 65 percent. Ginger that has been chilled softens, shrivels readily, and oozes moisture from the surface. Information in *12* suggests that 2 to 3 weeks' storage at 7° or lower seriously damages the rhizomes. See also *688*.

Greens, Leafy (Collards, Kale, Rape, Swiss Chard, and Beet Greens)

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Leafy greens are handled like spinach. Because of their perishability, they should be held as close to 0°C as possible. At this temperature, they can be held for 10 to 14 days. Relative humidity of at least 95 percent is desirable to prevent wilting. Air circulation should be adequate to remove heat of respira-

tion, but rapid air circulation will speed transpiration and wilting. Satisfactory precooling is accomplished by vacuum cooling or hydrocooling. These leafy greens are commonly shipped with package and top ice to maintain freshness. Research has shown that kale packed in polyethylene-lined crates and protected by crushed ice keeps in excellent condition for 3 weeks at 0° but only 1 week at 4° and 3 days at 10° (*409*). Vitamin content and quality are retained better when wilting is prevented (*234, 235*).

Horseradish

(Temperature, −1° to 0°C (30° to 32°F); relative humidity, 98 to 100 percent)

Horseradish should keep satisfactorily for a year at −1° to 0°C and very high relative humidity. A high relative humidity is essential for minimum deterioration during storage (*406*). Perforated plastic bags or bin liners can aid in maintaining the high humidity. Roots should be kept in the dark because they can become green when exposed to light. Roots dug when the plant is actively growing do not keep as well as those conditioned by cold weather before they are dug. Frequent inspection in storage is advisable. Horseradish can also be stored over winter in cool cellars or in outdoor pits or trenches (*968*).

Jicama

(Temperature, 13° to 18°C (55° to 65°F); relative humidity, 65 to 70 percent)

Jicama is a tropical root crop and is susceptible to chilling injury. It can keep 1 to 2 months at 13° to 18°C. Serious losses can be expected when it is stored at low temperatures (*133*), and sprouting may become a problem when it is kept at temperatures above 18°C. Maintaining a relative humidity of 65 to 70 percent is important to reduce postharvest decay (*133*). Hypochlorite dips also can effectively reduce decay.

Kohlrabi

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

Topped kohlrabi should keep for 2 to 3 months if stored under the recommended conditions. Some space between containers for air circulation is desirable, and a high relative humidity is recommended to prevent shriveling and toughening of the texture. Packaging in perforated film can be used to reduce moisture loss. Kohlrabi with leaves has a storage life of only 2 weeks at 0°C.

Storage should be at or near 0°C to prevent the development of diseases. Major storage diseases are bacterial soft rot and black rot (*749*).

Leeks

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Leeks, if properly handled, should keep satisfactorily for 2 to 3 months at 0°C. Storage conditions are similar to those for celery and green onions. Leeks should be cooled promptly after harvest to near 0° by hydrocooling, crushed ice, or vacuum cooling; and they should be kept at that temperature with high relative humidity (95 percent or above) throughout storage. Yellowing and decay develop rapidly at warmer storage temperatures. High relative humidity is essential to prevent wilting (*485, 975, 980*). Moderate wilting will be noted when leeks lose about 15 percent of their weight after harvest. The use of polyethylene-film crate liners and of crushed ice can aid in preventing moisture loss. In one series of tests (*412*), freshly harvested and trimmed leeks prepackaged in sealed, nonperforated polyethylene bags held up well for 10 weeks at 0° under crushed ice. No off-odors, off-flavors, or tissue injury from carbon dioxide buildup or oxygen depletion were found in leeks in the sealed packages.

Good refrigeration will retard the elongation and curvature that develop in leeks at 10° or 21°C (*412*). Respiration or heat evolution of leeks is about eight times faster at 21° than at 0°.

Storage for 4 to 5 months at 0°C is possible by using a controlled atmosphere (CA), although there will be some loss in quality (*398, 486, 932, 975*). The best CA contains from 1 to 3 percent oxygen and from 5 to 10 percent carbon dioxide. This CA retards yellowing and decay. Atmospheres containing 15 to 20 percent carbon dioxide cause tissue injury (*398*).

Cultivar, preharvest and postharvest conditions, degree of trimming, and method of packing will all influence the storage life of leeks.

Lettuce

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

Lettuce should be precooled to 1°C soon after harvest and stored at 0° and 98 to 100 percent relative humidity for retention of quality and shelf life. Precooling is commonly done by vacuum cooling (*66*) because it is more effective and rapid than hydrocooling. Also, since most head lettuce is field packed in corrugated cartons, vacuum cooling is more suitable. For vacuum cooling, containers and film wraps should be perforated or readily permeable to water vapor. To aid vacuum cooling, clean water is sprinkled on the heads of lettuce prior to carton closure if they are dry and warmer than 25°. Thorough precooling is essential because mechanically refrigerated rail cars or trucks do not have enough cooling capacity to cool warm lettuce during transit.

Lettuce is highly perishable and deteriorates rapidly with increasing temperature (fig. 6). The respiration rate increases greatly and storage life decreases concomitantly as the storage temperature increases over the temperature range from 0° to 25°C (*648*). Leaf lettuce respires at about twice the rate of head lettuce (*817*). At 0°, head lettuce can be held in good condition for 2 to 3 weeks, the time period depending on maturity, quality, and handling con-

dition of lettuce at harvest. The storage life at 3° is only about half of that at 0°.

Lettuce is easily damaged by freezing, so all parts of the storage room must be kept above the highest freezing point of lettuce (−0.2°C).

Controlled atmosphere is of limited benefit to the storage quality of lettuce (*521, 524*). Low oxygen levels of 1 to 8 percent can reduce russet spotting in susceptible lots. A 3-percent oxygen (O_2) and 1.5-percent carbon dioxide (CO_2) atmosphere maintains the appearance of lettuce and inhibits pink rib and butt discoloration better than air, but the effect is not noticeable after the lettuce is held at 10° in air for 5 days. Oxygen below 1 percent is injurious, as is CO_2 above 2.5 percent (*112, 445, 524, 536, 923*). High CO_2 levels cause brown stain, which may develop after lettuce is transferred to 10° air. Brown stain caused by high CO_2 is intensified when O_2 is reduced to 2 or 3 percent, but the degree differs with cultivar (*113*). If lettuce needs to be in transit overseas for a month, an atmosphere of 2 percent CO_2 and 3 percent O_2 is recommended, because the reduction in decay achieved by 2 percent CO_2 outweighs the danger of injury (*789*).

Lettuce should be held at high relative humidity, 98 to 100 percent. Film liners or individual polyethylene head wraps are desirable for attaining high relative humidity; however, they should be perforated or be permeable to maintain a noninjurious atmosphere and to avoid 100 percent relative humidity on removal from storage. Romaine and leaf lettuce appear to tolerate a slightly higher CO_2 level when packaged than head lettuce (*9*).

Russet spotting, which occasionally causes serious losses (*145*), is usually not a problem at temperatures below 2°C. Lettuce should not be stored with apples, pears, cantaloups, or other products that give off ethylene, as this gas increases russet spotting (*775*). (See also p. 28.) Hard lettuce heads are more susceptible to this disorder than firm lettuce. Storage in a low-oxygen atmosphere (1 to 8 percent) is very effective in controlling russet spotting (*521*).

Bacterial soft rot, the most serious disease of lettuce, often starts on bruised leaves, but it is much less serious at 0°C than at higher temperatures (*748*). Tipburn is also a major market disease of lettuce. It is of field origin, but occasionally increases in severity after harvest (*519*).

Melons

Cold storage is little used for melons except to avoid temporary adverse market conditions.

Cantaloups

(Temperature, 2° to 5°C (36° to 41°F); relative humidity, 95 percent)

Cantaloups ("muskmelons"[1]) harvested at the hard-ripe stage (3/4- to full-slip) can be held about 15 days at 2° to 5°C, but lower temperatures for this period may cause chilling. Symptoms of chilling injury are pitting and surface decay. Full-slip cantaloups are more resistant to chilling injury and can be held 5 to 14 days at 0° to 2°C. Soluble solids content of cantaloups at harvest should be at least 9 or 10 percent for good dessert quality (*789*). Cantaloups ripen after harvest but do not increase in sugar content. Cantaloups need precooling soon after harvest to reduce high field temperatures, and this can be done with cold water, cold air, or ice (*789, 915*). The choice depends primarily on economic factors and type of container. Hydrocooling is the most efficient method for rapidly cooling cantaloups, and they should be cooled to at least 10° to 15° (*789*). Warm, wet melons are subject to invasion by micro-organisms. Therefore, precooled melons should immediately be packed and shipped in refrigerated containers or stored in the cold room. Crushed ice is still used to remove field heat from cantaloups. Ice is blown in between rows of crates or waxed cartons and over a load packed for shipment. Although melons are chilling sensitive, they are not injured by extended contact with ice (*789, 921*).

Hot water (55°C) dipping for 30 seconds can reduce stem-scar and surface mold (*916*). (See also *679, 749.*)

Honey Dew, Casaba, Crenshaw, and Persian Melons

(Temperature, 7° to 10°C (45° to 50°F); relative humidity, 90 percent)

These melons are chilling sensitive and should not be held below 5°C. The best prolonged holding temperature is 7° for Honey Dew, Crenshaw, and Persian melons, and 10° for Casaba melons. The Crenshaw and Persian melons should keep for 2 weeks, and Honey Dew and Casaba melons for 3 weeks, before the quality of the ripened melons becomes unacceptable. These melons may keep longer, but with extended holding, they may fail to ripen or may ripen but fail to develop the desirable flavor and aroma. When melons are stored too long or at too low a temperature, they deteriorate (decay, surface breakdown, softening, or off-flavors) so rapidly upon transfer to room temperature that they soon become worthless. Honey Dew melons are less perishable than most other melons. Storage at as high as 18° has been recommended for them (*276*).

Honey Dew melons are usually given an 18- to 24-hour ethylene treatment (5,000 p/m) to ripen uniformly (*458, 735, 737*). Lower concentrations (40 to 1,000 p/m) have proved effective experimentally (*738*). Pulp temperature should be 20°C or above during treatment. Honey Dew melons must be mature when harvested; immature melons fail to ripen even if treated with ethylene. Honey Dew melons are less sensitive to chilling injury as the fruit ripens (*526, 527*), and a 24-hour treatment with 1,000 p/m ethylene will ripen the fruit sufficiently to make it less sensitive to chilling injury (*527*).

(See also *736, 749, 789, 1033.*)

[1]Commercially, the term "muskmelon" is often used synonymously with "cantaloup." This usage is not botanically precise, as the muskmelon (*Cucumis melo* L.) includes Honey Dews, Casabas, Crenshaws, and Persian melons as well as cantaloups.

Watermelons
(Temperature, 10° to 15°C (50° to 60°F); relative humidity, 90 percent)

Watermelons are not adapted to long storage. At low temperatures they are subject to various symptoms of chilling injury and loss of quality, and at high temperatures they are subject to decay. Between 10° to 15°C is a good compromise. Watermelons should keep at this temperature range for 2 to 3 weeks; some will keep longer. Melons held 6 weeks at room temperature will have poor flavor.

Watermelons should be consumed within 2 to 3 weeks after harvest, primarily because of the gradual loss of crispness. Quality in watermelons is determined largely by high sugar content, a deep red flesh color, and a pleasant crisp texture of the edible flesh (*837, 674*). These factors are dependent on maturity, cultivar, and handling methods. Commercial melons for distant market are usually harvested when mature, but before full ripeness, to minimize handling damage and flesh breakdown. They are at their best for eating when mature but preclimacteric (*635*). Immature melons have a pink flesh, mature melons are red to dark red, and overmature ones have orange flesh (*837*). Actually, the red color and flavor of watermelons improve during storage for 7 days at or above room temperature, while at 10°C or below color fades. The decrease in redness may be due to chilling, since these melons develop other symptoms of chilling, such as pitting and loss of flavor, at low temperatures (*835*).

In tests with Florida watermelons stored at 7°, 10°, and 16°C for 2 weeks, chilling injury was observed during and after storage at 7° and 10°. No chilling was observed in melons held at 16° (*215*). Decay, mainly black rot, was always higher on melons previously stored at 7° or 10° than on those held at 16°, and it developed mainly after storage. Although decay is usually not a major form of deterioration, extended storage at warm temperature (24°) will result in more decay than at cooler temperatures (*506*).

Watermelons are sensitive to high levels of ethylene gas during storage, as it hastens loss of firmness. Melons exposed to 30 or 60 p/m ethylene for 7 days at 18°C were unacceptable for eating (*763*). Even at the relatively low concentration of 5 p/m ethylene, watermelons will become less firm and less acceptable. Watermelons should not be stored or shipped with fruits that emit substantial amounts of ethylene.

Rough handling will result in serious losses. Watermelons should not be dropped, thrown, or walked on, as internal bruising and flesh breakdown will occur. Cartons holding three to five melons and bulk bins with pallets, if used, can speed handling and minimize melon damage.

Storage and marketing diseases (black rot, phytophthora rot, rhizopus rot, stem-end rot, and so forth) are discussed in *749, 506*.

Mushrooms, Cultivated

(Temperature, 0°C (32°F); relative humidity, 95 percent)

Fresh mushrooms do not keep well in storage and are, therefore, stored only for a short period. Deterioration is marked by brown discoloration of the surfaces, elongation of the stalks, and opening of the veils. Freshly picked mushrooms will keep in prime condition at 0°C for 5 days, at 4.5° for 2 days, and at 10° for only 1 day. If allowance for a marketing period of 1 day at higher temperatures immediately after storage is made, mushrooms should be kept at 0° for only 3 to 4 days and at 4.5° for about 1 day. While being transported or displayed for sale, mushrooms should be kept refrigerated. Dehydration is correlated with black stems and open veils (*419*). Moisture-retentive film overwraps or film caps usually are beneficial in reducing moisture loss. Deterioration of mushrooms can be retarded in overwrapped prepacks (*671*). Treatment with a solution of salt and sodium bisulfite has been found effective in reducing discoloration (*279, 419*). Controlled atmospheres with 5 to 10 percent carbon dioxide, low-pressure storage at 10 to 15 mm Hg, and gamma irradiation have all shown promise for maintaining whiteness and prolonging the useful life of mushrooms (*109, 210, 789*).

Okra

(Temperature, 7° to 10°C (45° to 50°F); relative humidity, 90 to 95 percent)

Okra deteriorates rapidly and is normally stored only briefly to hold for marketing or processing (*817, 1055*). Large quantities are canned, frozen, or brined. It has a very high respiration rate at warm temperatures and should therefore be promptly cooled to retard heating and subsequent deterioration.

Okra in good condition can be stored satisfactorily for 7 to 10 days at 7° to 10°C. At higher temperatures toughening, yellowing, and decay are rapid. A relative humidity of 90 to 95 percent is desirable to prevent shriveling. At temperatures below 7° okra is subject to chilling injury, which is manifested by surface discoloration, pitting, and decay. Holding okra for 3 days at 0° may cause severe pitting. Contact or top ice will cause water spotting in 2 or 3 days (*1055*).

Fresh okra bruises easily, the bruises blackening within a few hours. A bleaching type of injury may also develop when okra is held in hampers for more than 24 hours without refrigeration (*1055*). Storage containers should permit ventilation.

Prepackaging in perforated film is helpful both to prevent wilting and physical injury during handling. Results of a packaging study suggest that 5 to 10 percent carbon dioxide in the atmosphere lengthens shelf life by about a week (*34*). Higher concentrations of carbon dioxide caused off-flavors.

Onions

Dry Onions

(Temperature, 0°C (32°F); relative humidity, 65 to 70 percent)

Onions are held in either common or cold storage. The storage quality of onions is influenced by cultivar and by the conditions under which they are grown (*564, 949, 993, 1069*).

Onions should be adequately cured in the field, in open sheds, or by artificial means before or in storage. Adequate curing in the field or in open sheds may require 2 to 4 weeks, depending on the weather. The best skin color develops at 24° to 32°C. The commonest method of curing in northern areas is by forced ventilation in the storage by blowing heated air at 27° to 35° through the onions (*188, 201*). In Florida or other Southern States where field curing is infeasible, curing with forced heated air at 35° for 48 hours is effective (*124*). Electric or gas-fired infrared radiation has been shown to be an effective heating system for rapid curing (*124, 776*). Onions are considered cured when the neck is tight and the outer scales are dry and will rustle. This condition is reached when onions have lost 3 to 5 percent of their weight. If not adequately cured, onions are likely to decay in storage (*121, 430, 776, 985*). The commonest form of decay is gray mold rot, which occurs at the top of the bulb—whence its name "neck rot." High temperatures and high humidity (80 percent) during curing with good air circulation favor development of desirable skin color (*188, 430*).

In the northern onion-growing States, onions of the globe type are generally held in common storage. Average winter temperatures in the principal northern onion-producing States are sufficiently low to permit common storage during the winter months. However, they should not be held after early March unless they have been treated with maleic hydrazide in the field to reduce sprout growth (*430*).

Refrigerated storage is often used for onions to be marketed late in the spring. Onions to be held in cold storage should be placed there immediately after curing. A temperature of 0°C will keep onions dormant and reasonably free from decay, provided the onions are sound and well cured when stored. Air circulation should be sufficient to prevent heating and to remove moisture from within bins or sacks. Sprout growth indicates too high a storage temperature, poorly cured bulbs, or immature bulbs. Root growth indicates too high a relative humidity. A comparatively low relative humidity (65 to 70 percent) is recommended for successful storage of onions. However, humidities as high as 85 percent and forced-air circulation have given satisfactory results. Higher humidities, at which most other vegetables keep best in storage, dispose onions to root growth, rot, and surface mold (*927, 978*).

Globe onions can be held for 6 to 8 months at 0°C (*188, 201, 1069*).

The mild, or Bermuda, types, such as those produced in Washington, southern California, Texas, and other States where the climate is not suitable for common storage, are usually consumed soon after harvest. These onions can be held in cold storage; but, because of their poorer keeping qualities, they usually are stored for much shorter periods than the globe cultivars. Bermuda onions can usually be held at 0°C for only 1 to 2 months.

Onions of the Spanish type grown in the United States are often stored; if well matured, they can be held at 0°C at least until January or February (4 to 5 months). In California, onions of the sweet Spanish type are held at 0° until April or May.

Onions will sprout and decay rapidly when stored at temperatures between 5° and 20°C. However, they will not sprout or be as susceptible to decay if they are in the resting stage, which lasts 30 to 60 days. The resting of most cultivars is completed during storage at 0°.

Onions are damaged by freezing, the damage appearing as water soaked scales when the thawed onions are cut (*851*). Onions only slightly frozen may recover with little perceptible injury if allowed to thaw slowly and without handling.

Translucent scale of onions (a clearing of the scales which somewhat resembles freezing injury) has been found in California, the Northeast, and the Great Lakes areas, particularly in large bulbs stored several months. Prompt cold storage after curing reduces its prevalence (*529*).

Onions are stored in 23-kg (50-lb) bags, in crates, in pallet boxes that hold about a half ton of loose onions, or in bulk bins. Bags of onions are frequently stored on pallets and should be stacked to allow proper air circulation. Modern air-cooled storages have forced-ventilation systems in which air, heated if necessary, is introduced through floor racks beneath the bins of onions. Onions in bins are stored about 3 to 4.6 meters (10 to 15 ft) deep, but soft onions at the bottom may be distorted in shape.

Onions should not be stored with other products that tend to absorb odors. They may be stored with garlic.

When onions are removed from storage in warm weather, they are apt to sweat because of moisture condensation. This may favor decay. Warming onions gradually—for example, to 10°C over 24 to 36 hours—with good air movement should avoid this difficulty.

Onions can also be stored at high temperatures of 30° to 35°C for short periods before marketing or before processing (*960*). Dehydrated flakes produced from onions that had been stored at 30° for 4 months discolored less in storage than flakes made from onions stored at cold temperatures (*1076*).

Controlled-atmosphere-storage tests with onions have been only moderately successful. An atmosphere of 5 percent carbon dioxide with 3 percent oxygen reduced losses from sprouting and root growth (*7*).

(See *851* and *993* for a discussion of onion diseases. See *188* for further information on construction and operation of storages for northern-grown onions.)

Green Onions
(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Green onions (scallions) and green shallots are quite perishable and are normally marketed promptly. They can be stored 3 to 4 weeks at 0°C if moisture loss is prevented. Crushed ice spread over the onions aids in supplying moisture (*410, 509*). Packaging green onions in perforated polyethylene film also will aid in preventing moisture loss. Storage life at 5° for green onions is only about 1 week. Higher temperatures favor more rapid yellowing and decay of the leaves.

Vacuum cooling is effective for removing field heat, but the onions should be wetted first and packed in polyethylene-lined cartons to minimize moisture loss.

For maximum storage, a controlled atmosphere of 1 percent oxygen with 5 percent carbon dioxide at 0°C should allow 6 to 8 weeks' storage. However, the green onions must be properly packed in waxed cartons or poly-lined containers (*410*). The freezing point of green onions is about −1°.

Onion Sets

(Temperature, 0°C (32°F); relative humidity, 65 to 70 percent)

The temperature and humidity requirements for onion sets, used primarily as planting stock for early green onions, are essentially the same as those for large dry onions. Because of their small size, onion sets tend to pack closely; so they should not be placed into deep piles. They are usually held in ventilated storage in shallow, slatted trays rather than in bags or crates. They are handled in mesh or kraft paper bags for marketing. Low relative humidity and low temperature are important to keep the sets sound and dormant and free from sprouting and rooting (*1069*). At humidities much above 70 percent and at warmer temperatures (4° to 10°C), more of the sets will sprout, develop roots, and decay. Onion sets should be stacked to allow good air circulation. A storage life of 6 to 8 months is possible for good quality sets.

Parsley

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Parsley should keep 2 to 2.5 months at 0°C (*417*). High humidity is essential to prevent desiccation. Packaging in perforated polyethylene bags and using top ice are often beneficial. A controlled atmosphere of 10 percent oxygen and 11 percent carbon dioxide can help retain green color and salability (*49*).

Root or hamburg parsley can be stored like carrots or parsnips. With the top removed, root parsley should keep several months at 0°C.

Parsnips

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

Parsnips have nearly the same storage requirements as topped carrots and should keep for 4 to 6 months at 0°C. Only sound, healthy roots should be stored—never bruised or damaged ones. The main storage problems with parsnips are decay, surface browning, and their tendency to shrivel. The surface browning or yellowing is due to enzymatic oxidation of phenolic compounds (*154*). Refrigeration will retard both the discoloration and decay.

Parsnips may be subjected to a considerable amount of freezing without serious damage. For example, roots exposed at −7°C for 3 hours showed little damage other than slight softening and discoloration when thawed over 24 hours at 21° (*693*). However, they should be protected from hard freezing and should be handled with great care while frozen. Parsnips held at 0° to 1° for 2 weeks after harvest attain a sweetness and high quality equal to that of roots subjected to frosts for 2 months in the field (*103*). Parsnips dry out readily in storage; hence, it is essential that the humidity of the storage be kept high. They will remain crisper and firmer, with less weight loss and better color, if stored at a relative humidity of 98 to 100 percent rather than 90 to 95 percent. In Canadian research (*979*), a jacketed type storage provided optimum conditions for parsnip storage. Ventilated polyethylene crate liners aid in preventing moisture loss. Waxing is not particularly effective in preventing wilting and may hasten browning (*721*).

Storage diseases (gray mold, parsnip canker, bacterial soft rot, and watery soft rot) are discussed in *302, 851*.

Peas

Green Peas
(Temperature, 0°C (32°F); relative humidity, 95 to 98 percent)

The popularity of green peas for fresh market has decreased markedly in the past 40 years because of harvest expense and the availability of frozen peas.

Green peas tend to lose part of their sugar content, on which much of their flavor depends, unless they are promptly cooled to near 0°C after picking. Hydrocooling is the preferred method of precooling. Peas packed in baskets can be hydrocooled from 20° to 2° in about 12 minutes when the water temperature is 0° (*789*). Vacuum cooling also is possible, but the peas must be prewet to obtain cooling similar to that by hydrocooling. After precooling, peas should be packed with crushed ice (top ice) to maintain freshness and turgidity. Adequate use of top ice provides the required high humidity (95 percent) to prevent wilting (*789, 917*). The ideal holding temperature is 0° (*437, 722*). Peas cannot be expected to keep in salable condition for more than 1 to 2 weeks even at 0° unless packed in crushed ice. With ice, the storage period may be extended perhaps a week. Peas keep better unshelled than shelled (*992*).

Research in England showed that the edible quality of green peas was maintained better when the peas were held in a modified atmos-

phere of 5 to 7 percent carbon dioxide at 0°C than in air for 20 days (*953*).

Southern Peas
(Temperature, 4° to 5°C (40° to 41°F); relative humidity, 95 percent)

Freshly harvested southern peas at the mature-green stage should have a storage life of 6 to 8 days at 4° to 5°C with high relative humidity. Without refrigeration, they remain edible only about 2 days, the pods yellowing in 3 days and showing extensive decay in 4 to 6 days (*440*). Refrigerated storage retards the loss of ascorbic acid and nonreducing sugars. Without refrigeration these losses begin immediately after harvest.

Large quantities of shelled southern peas are now processed by freezing, and lesser quantities are canned. Shelled peas are much more perishable than peas in the pod and will retain good marketable quality for only about 24 hours at 4° to 5°C. Peas to be trucked to processing plants are shelled into bins in the field, where temperatures may approach 38°. Studies have shown that the peas lose green color, turn yellow, and start to decay in only a few hours at 25° (*871, 873*). Flavor deterioration and off-flavor in the shelled peas may be a problem if they have to be held as much as 7 hours at 30° before processing. Cooling the peas, as by hydrocooling, soon after harvest followed by refrigeration is the most effective method of maintaining a high quality product. The shelled peas need to be cleaned to remove trash before hydrocooling. However, cleaning and hydrocooling facilities are not available in most production areas, so commercial application is limited (*872*).

Peppers

Chili and Other Hot Peppers
(Temperature, see text; relative humidity, 60 to 70 percent)

Chili peppers are usually picked when ripe and are then dried and allowed to equalize in moisture content in covered piles. Water is usually added to the peppers after drying to reduce brittleness. They are then packed tightly into sacks holding 200 or more pounds and are generally stored in nonrefrigerated warehouses for up to 6 months. The temperature of the warehouses depends to some extent on their construction and the way in which they are managed but chiefly on the outside temperature (10 to 25°C). Insect infestation is a major storage problem. In Southern States, chili and other hot peppers are dried, packaged, and then stored at 0° to 10° until shipped to processing plants. Storage at low temperatures aids in retarding the loss of red color and in slowing down insect activity.

The moisture content of chili and other hot peppers when stored should be low enough (10 to 15 percent) to prevent mold growth. A relative humidity of 60 to 70 percent is desirable. With a higher moisture content the pods may be too pliable for grinding and may have to be redried. With lower moisture content (under 10 percent) pods may be so brittle they shatter during handling; this causes losses and the release of dust, which is irritating to the skin and respiratory system.

The use of polyethylene film liners within bags allows better storage and reduces the dust problem. The liners ensure that the pods maintain a constant moisture content during storage and up until the time of grinding; thus, they permit successful storage or shipment under a wide range of relative humidities (*1060*). Packed in this manner, peppers can be stored 6 to 9 months at 0° to 4°C.

Manufacturers of chili and other hot pepper products hold part of their supply of the raw material in cold storage at 0° to 10°C, but they prefer to grind the peppers as soon as possible and store them in the manufactured form in airtight containers.

Freshly harvested chili or other hot peppers should be stored under the same temperature and humidity conditions as those for sweet peppers.

Sweet Peppers
(Temperature, 7° to 13°C (45° to 55°F); relative humidity, 90 to 95 percent)

Sweet, or bell, peppers are subject to chilling injury at temperatures below 7°C, and temperatures above 13° encourage ripening and spread of bacterial soft rot. Bell peppers should not be stored longer than 2 to 3 weeks even under the most favorable conditions. At 0° to 2° peppers usually develop pitting in a few days. Peppers held below 7° long enough to cause serious chilling injury also develop numerous lesions of alternaria rot. *Alternaria* causes the calyx to mold and decay (*604, 647*). Holding at 4.5° and below predisposes peppers to botrytis decay also (*610*).

Rapid precooling of harvested sweet peppers is essential in reducing marketing losses, and it can be done by forced-air cooling, hydrocooling, or vacuum cooling. Properly vented cartons are recommended to facilitate forced-air cooling. If hydrocooling is used, care should be taken to prevent the development of decay.

Sweet peppers prepackaged in moisture-retentive films, such as perforated polyethylene, have a storage life at 7° to 10°C up to a week longer than nonpackaged peppers (*35*). The use of film crate liners can help in reducing moisture loss from the fruit.

It is commercial practice to wax peppers; only a thin coating should be applied. Waxing provides some surface lubrication, which not only reduces chafing in transit but also reduces shrinkage; the result is longer storage and shelf life (*355*). Senescence of sweet peppers is hastened by ethylene. Therefore, it is not a good practice to store peppers with apples, pears, tomatoes, or other ethylene producing fruits in the same room.

Low-oxygen (3 to 5 percent) atmospheres retard ripening and respiration during transit and storage (*645*). High concentrations of carbon dioxide delay the loss of green color. However, high carbon dioxide also causes calyx discoloration (*994*).

Potatoes

Early-Crop Potatoes

(Temperature, see text; relative humidity, 90 to 95 percent)

Early-crop, or summer-harvested, potatoes grown in the Southern or Western States usually are not stored except briefly. Such tubers are quite perishable, as they bruise easily and have an easily abraded immature skin. Early potatoes that are free from serious bruising and decay can be held 4 to 5 months at 4°C for table use if they are cured 4 or 5 days at 15° to 21° to heal slight wounds before storage. However, early-crop potatoes are usually marketed immediately to take advantage of favorable prices. A relative humidity of 90 to 95 percent in the ventilating air is desirable. Careful handling to avoid injury and avoidance of exposure to sun and heat during harvesting and handling minimize losses. (See *551, 778, 942*.)

Part of the early-crop potatoes are used for making chips. Holding these potatoes in cold storage even at moderate temperatures of 10° to 13°C for only a few days causes excessive accumulation of reducing sugars, which results in production of undesirably dark-colored chips. Conditioning of these potatoes at 21° or higher after cold storage usually fails to lighten chip color appreciably. Storage temperatures near 21° are required to maintain chipping quality but shorten storage life. Still higher temperatures cause excessive decay.

Late-Crop Potatoes

(Temperature, see text; relative humidity, 90 to 95 percent)

Most late-crop potatoes produced in the northern half of the United States are stored. The greater part of the crop is held in nonrefrigerated, common, air-ventilated farm storages; but some potatoes are stored in refrigerated warehouses. Potatoes in nonrefrigerated storage are usually in bulk piles or bulk bins 2.5 to 6 meters (8 to 20 feet) deep. Some potatoes are stored in pallet boxes (*386*). Pressure bruises and internal black spot are substantially reduced by this method of storage. In cold-storage warehouses, potatoes can be stored in sacks, pallet boxes, or bulk. Since many cultivars are grown in all 50 States, only general storage recommendations can be given. Growing and harvesting conditions influence the behavior of potatoes in storage.

The purpose of potato storage is to maintain tubers in their most edible and salable condition and to provide a uniform flow of tubers to market and processing plants throughout fall, winter, and spring. Good storage should prevent excessive loss of moisture, development of rots, and excessive sprout growth. It should also prevent accumulation of a high concentration of sugars in potatoes, which results in dark-colored processed products (*852*). A potato storage should have adequate insulation, outside waterproofing, inside vaporproofing, ventilation, air distribution, an adequate humidification system, and properly designed controls for temperature and ventilation (*138, 423, 904*). Temperature, humidity, and air movement are the most important factors during storage. Temperature requirements are governed by the intended use of the potatoes. They should always be kept in the dark; very small amounts of light will gradually cause greening. Lights should not be left on in storage any longer than necessary. Surface greening is due to chlorophyll formation and is harmless. However, its presence in potatoes is undesirable because at times an alkaloid called solanine is formed with the chlorophyll. Solanine, or perhaps the total glycoalkaloids, causes potatoes to have a bitter or undesirable flavor. Little greening develops in the light at 4°C or below but develops rapidly at 20° (*431*). Other treatments that inhibit greening include spraying with lecithin (*1073*), dipping in oil, and vacuum infiltrating with calcium.

Immediately after harvest, potatoes should be cured by holding at 10° to 15.5°C (50° to 60°F) and high relative humidity for 10 to 14 days to permit suberization and wound periderm formation (healing of cuts and bruises) (*55*). Although wound periderm formation is most rapid at about 21°, lower temperatures are recommended, as decay is less likely to occur. Curing reduces subsequent weight loss and also the danger of rot by preventing the entry of *Fusarium* and other rot organisms. The relative humidity during curing should be about 95 percent. In some areas, the high humidity requirement can be met by leaving the potatoes in storage without any ventilation, provided there are no disease problems (*134, 814*).

After potatoes for seed or table stock are cured, they should be held at 3.5° to 4.5°C (38° to 40°F). The minimum rate of respiration has been found to occur at 3°. Storage at 4° is considered optimum for numerous cultivars for maximum storage life because sprout growth is absent or negligible, shrinkage is low, and other losses are usually minimized. At temperatures below 3°, potatoes are chilled and tend to become undesirably sweet. Storage at 0° to 1° for 20 weeks or longer causes some cultivars to show mahogany browning, a symptom of chilling injury (*869*). Potatoes are easily damaged by freezing; therefore, low-temperature storage permits little leeway if circulation is inadequate to maintain uniform temperatures throughout the storage. The highest freezing point of potatoes is about −1°. Most potatoes will remain dormant during 5 to 8 months of storage at 4°. If longer storage is desired, as it often is with seed stock, potatoes should be stored at 3°. A range of 4° to 7° is suggested for potatoes to be marketed by December 1.

Storage at 7°C (45°F) with 95 percent relative humidity is recommended for table stock Russet Burbank potatoes. Under these conditions tubers of Russet Burbank treated with a sprout inhibitor will remain sprout free and of high quality for 10 to 12 months (*183, 424, 904, 905*). Katahdin and Kennebec grown in the late-summer production areas of New Jersey, Pennsylvania, and Long Island develop less black

spot if treated with a sprout inhibitor and stored at 10° rather than 4° (*809*).

Potatoes that are particularly susceptible to fresh bruises or internal black spot are injured less if their temperature is raised to about 10° before grading. However, if the bins are not independently controlled, the rise in temperature may be detrimental to potatoes in adjoining bins.

The optimum temperature range for storing most cultivars of potatoes to be processed into chips or french fries is 10° to 13°C (*547, 852, 942*). A desirable relative humidity for holding potatoes for processing is 95 percent to minimize weight loss. Russet Burbank potatoes for processing are held at 7° (*904, 905*). Potatoes that have been stored at 4° or below are seldom suitable for processing—for example, chip making, french frying, or dehydrating—without first being reconditioned to reduce the quantity of reducing sugars that have accumulated. Reconditioning is accomplished by holding potatoes at about 18° to 21° until trial cooking tests show that they have recovered sufficiently for use. The length of the conditioning period depends on the amount of reducing sugars that have accumulated; usually it is 1 to 4 weeks. Some lots of potatoes fail to condition properly after storage at 4°, as they have too high a reducing-sugar content at harvest to make satisfactory chips.

Slightly higher reducing-sugar content is desirable in potatoes for french frying than in potatoes for chip making. Potatoes for frozen french fries can usually be stored at temperatures of 7° to 10°C and fried without further conditioning or at 4° to 6° and conditioned before frying. Occasional lots of potatoes can be fried directly out of 4° to 6° storage. Desirable storage temperature depends on the particular method used by the processor in french frying.

Relatively little information is available on temperature requirements for potatoes to be dehydrated. For flake production, the suggested steps for handling the pototoes are treatment with a sprout inhibitor, storage at 4° to 7°C, and then conditioning or continuous storage at 10° (*808*). These practices lower the reducing-sugar level; high sugars adversely affect the shelf life of the flakes.

Potatoes usually do not sprout until 2 to 3 months after harvest even at 10° to 15°C. However, after 2 to 3 months' storage, sprouting can be expected in potatoes stored at temperatures above 4° and particularly at temperatures around 15° Although limited sprouting does not seriously damage potatoes for food purposes, badly sprouted stock shrivels and is difficult to handle and market. Certain growth-regulating chemicals have been approved by the U.S. Food and Drug Administration to control or reduce sprouting on potatoes. One of these, maleic hydrazide, is applied on the plants in the field 2 to 4 weeks before harvest. Also extensively used is CIPC (isopropyl *N*-(3-chlorophenyl) carbamate), which is applied to the potatoes after harvest, usually after a period in storage to avoid interference with curing (wound healing). A combination spray of CIPC, thiabendazole, and chlorine applied to potatoes at time of storage overcomes this detrimental effect of CIPC and also reduces fusarium rot (*501*). CIPC can also be applied as the potatoes are removed from storage to control sprouting during marketing. Gamma irradiation, at 0.05 to 0.15 kgray, is also approved for use to inhibit sprouting. These chemicals or irradiation should not be used on seed potatoes, as they retard sprouting or may prevent it. The Extension crop specialist should be consulted on proper procedures for using chemicals and other methods for inhibiting sprouting.

Occasionally, field sprouting occurs in potatoes during periods of unusual drought or high temperatures. Such potatoes can be stored successfully, but it is especially important that they be cooled to 4°C rather quickly after curing and that the curing period be just a few days.

High relative humidities (90 to 95 percent) are required in potato storages. Usually, humidifiers will be needed to add water to the air. A humidifier is normally placed in the plenum chamber immediately behind the circulation fan. In this location, all of the air, whether it is recirculated or fresh incoming air, will pass over the humidifier (*547*). A humidity of 95 percent reduces weight loss and shrinkage markedly over humidities of 80 to 85 percent and generally results in better quality table potatoes and processed products (*134, 547, 902*). A relative humidity of 95 percent has been particularly recommended for Russet Burbank and Kennebec tubers (*547, 902*). Researchers on Long Island pointed out that a storage humidity in excess of 90 percent is hazardous and makes tubers more susceptible to rot if free moisture remains on their surface (*79*). Moisture condensation on tubers and on walls and ceilings should be avoided (*115, 134, 424*). Usually such condensation can be controlled by adequate ventilation and airflow. Canadian researchers have reported the optimum relative humidity for potato storage at 4° to 8°C to be 98 to 100 percent; decay was not higher than that at 85 to 90 percent relative humidity (*978*).

In years when late blight, leak (*Pythium* spp.), or field frost is severe, it is usually desirable to maintain a low humidity to keep the rotted tissue relatively dry and reduce spreading of the rot to other potatoes. Waxing potatoes is of little value for controlling shrinkage or improving appearance (*342*).

Ventilation or air circulation in potato-storage warehouses is needed to control temperature and humidity and to provide adequate oxygen for the respiring tubers. In Idaho, excellent results have been obtained with piles of Russet Burbank potatoes by ventilating with air at 95 percent relative humidity at a rate of 0.3 m^3 (10 ft^3)/minute/ton of potatoes on an intermittent basis (*903*). In Maine, an airflow of 0.3 to 0.4 m^3/minute/ton is recommended. In the Midwest, storages normally have an airflow of 0.6 to 0.7 m^3/minute/ton for seed and table stock potatoes and 0.8 to 1 m^3/minute/ton for chip stock (*852*). Rapid air circulation may result in lowering the

relative humidity of the air immediately surrounding the potatoes and may thus be conducive to drying and weight loss. These effects may be desirable if there are disease problems but are undesirable with sound potatoes because of increased shrinkage. Since conditions vary so greatly in the different States, guidance on ventilation and air circulation in commercial and farm potato warehouses should be obtained from local authorities.

Potatoes will impart an earthy flavor to apples and pears, so they should not be stored together.

Controlled-atmosphere storage has not been shown to lengthen the storage potential of table stock potatoes. Holding potatoes in 5 percent oxygen or less inhibits periderm formation and wound healing. In 1 percent oxygen, tubers develop off-flavors, increased decay, surface mold, and blackheart during only 1 week at 15° to 20°C (*522*). A low temperature (5°) lessens these deleterious effects but provides no distinct benefits of low oxygen. Blackheart frequently occurs if tubers are held at 32° (90°F) or higher during storage or transport. At such high temperatures insufficient oxygen reaches the interior of the tubers to sustain normal metabolism and respiration (*852*). Storage of Kennebec potatoes in 10 percent carbon dioxide or higher at 4° increased decay and did not lengthen storage life (*135*).

Information in the literature on the effects of controlled atmospheres on sugar accumulation and subsequent chip color is still inconclusive. Color was darker in chips made from potatoes stored in high carbon dioxide atmospheres (*135*). Others have reported that storage in 2.5 percent oxygen for 1 month at the chilling temperature of 1° substantially reduced sucrose accumulation in some cultivars over that of controls in air and that these tubers produced chips with acceptable color (*833*).

Seed potatoes are sometimes warmed to 15°C for several days just before shipping or during transit to stimulate rapid sprouting after planting (*134*).

For a discussion of potato diseases and disorders in storage, see *424, 852, 869, 970.* For additional information on various aspects of potato storage, see *416, 627, 752, 778, 815.*

Pumpkins and Squashes

Pumpkins and Winter Squashes

(Temperature, 10° to 13°C (50° to 55°F); relative humidity, 50 to 70 percent, see text)

Pumpkins and squashes are placed on racks, in bulk bins, or baskets and are held in ventilated or common storage in production areas. Most cultivars of pumpkins do not keep as well as hard-shelled winter squashes; both types of vegetables are subject to chilling injury at low temperatures. Such cultivars of pumpkins as Connecticut Field and Cushaw cannot be expected to hold in good condition more than 2 to 3 months at 10° to 13°C.

All winter squashes should be well matured, carefully handled, and free from injury or decay when stored. They should be kept dry, and storage rooms should have good air circulation (*402*). Relative humidities of 50 to 70 percent (60 percent may be optimum) are recommended for pumpkins and winter squashes, which are lower than those recommended for most vegetables. Higher humidities promote decay and lower humidities cause excess weight loss and texture deterioration (*789*).

Acorn-type squashes, such as Table Queen, should keep 5 to 8 weeks at 10°C. At higher temperatures (15° to 20°), Table Queen will lose greenness, become undesirably yellow, and acquire a stringiness of the flesh in 5 weeks. At 0° to 4° yellowing does not occur but chilling does. Alternaria rot develops on chilled squashes after their removal from storage (*603*). The popular Butternut squash should keep at least 2 to 3 months at 10°. Often it is stored for longer periods, but spoilage and shrinkage increase. Weight loss should be kept below 15 percent to minimize development of hollow neck, and a relative humidity of 50 percent is recommended (*253*). Turban and Buttercup squashes should keep at least 3 months.

The Hubbard squash, if in good condition initially, can be successfully stored 6 months at 10° to 13°C with 70 percent relative humidity. A 15-percent loss in weight from shrinkage for 6 months' storage would be average (*301*).

A 10- to 20-day curing period at 24° to 27°C before storage is sometimes recommended for pumpkins and winter squashes (*285*). However, experiments in New York showed that a preliminary curing for 3 weeks at 27° before storage to heal mechanical injuries and to ripen immature specimens was unncessary (*722, 811*). Curing Butternut, Hubbard, and Quality squashes was of no value but not harmful, whereas curing Table Queen was detrimental to skin color, texture, and taste (*811*). Cured Table Queen also decayed more rapidly than noncured fruit.

Less rot will develop in the Hubbard squash if stems are completely removed before storage. Hubbard squash and other dark-green-skinned squashes should not be stored near apples, as the ethylene from apples may cause the skin to turn orange yellow (*1077*). Black rot, dry rot, and bacterial soft rot are the principal causes of spoilage of winter squashes in storage (*301, 1077*).

Summer Squashes

(Temperature, 5° to 10°C (41° to 50°F); relative humidity 95 percent)

Summer squashes, such as Yellow Straightneck, Yellow Crookneck, White Scallop, Zucchini, and other soft-skin types are harvested at the immature stage for best quality. They are quite perishable, as the skin is tender and easily wounded in handling. Small fruits are more desirable than large ones because they have a more tender flesh and a slightly sweet flavor. Normally they should not be stored except long enough to accommodate normal delays such as holidays and weekends. They can be held 1 or 2 days below 5°C with no discernible damage, but such exposure should

be avoided as summer squash is chilling sensitive (*789*). Holding summer squash longer than 4 days at 0° will cause chilling damage and more rapid deterioration. The recommended temperature range is 5° to 10° with 95 percent relative humidity. The storage life of summer squash is only 1 to 2 weeks. If storage of yellow squash extends beyond a week and distribution is involved after removal, storage at temperatures of 7° to 10° is best. The storage period at 7° to 10° should be limited to 2 weeks or less (*545*). Recent research has shown that 5° is best for Zucchini squash stored up to 2 weeks (*621*). Storage in low-oxygen atmospheres was of little or no value for Zucchini squash held at 5°.

Radishes

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Most **spring radishes** are topped and packaged in plastic bags. They should be cooled quickly to 5°C or below to maintain their crispness. Hydrocooling is an effective method of cooling radishes (*922*). Black spot is reduced by washing radishes in chlorinated water (*827*). Topped radishes can usually be held for 3 to 4 weeks at 0° and a somewhat shorter time at 5°. They will keep at least a week at 7° (*555*). When temperatures are higher than 0°, low oxygen (1 percent) is beneficial in reducing top and root growth and softening (*525*). The regrowth of tops can be greatly retarded by trimming off the growing points, which are aggregated within a few millimeters on top of the root. Bunched radishes have a much shorter market life because of the perishability of the tops. They can be held at 0° and a relative humidity of 95 percent for 1 to 2 weeks (*720*). Addition of package and top ice aids in keeping the tops fresh.

Winter, or black, radishes require the same storage conditions as topped carrots and should keep in good condition for 2 to 4 months at 0°C.

Rhubarb

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Fresh rhubarb stalks in good condition can be stored 2 to 4 weeks at 0°C and high relative humidity. Rhubarb can be hydrocooled or air-cooled, and the temperature of the stalks should reach 0° or 1° within 1 day. The topped bunches or loose stalks should be packed in crates, and the crates should be stacked to allow ample air circulation; otherwise, there is danger of heating and mold growth. Rhubarb is usually marketed with about 5 to 6 mm (1/4 in) of the leaf attached to the petiole. Splitting of the petiole will be more serious if the entire leaf is removed. Moisture loss in storage will be much less if the bunched or loose stalks are packed in crates lined with perforated polyethylene film.

Fresh rhubarb cut into 2.5-cm (1-in) pieces and packaged in 450-g (1-lb) perforated polyethylene bags can be held 2 to 3 weeks at 0°C with high relative humidity (*168, 407*).

Rutabagas

(Temperature, 0°C (32°F); relative humidity, 98 to 100 percent)

Rutabagas require the same storage conditions as topped carrots and should keep satisfactorily for 4 to 6 months. Rutabagas lose moisture and shrivel readily if not stored under high humidity conditions. The optimum humidity is 98 to 100 percent or as close to saturation as possible (*979*). Canadian research showed that as compared with rutabagas stored at 90 to 95 percent relative humidity, those stored at higher humidities showed either less or about the same amount of decay, lost considerably less moisture, remained firmer, and had better color.

Waxing is not recommended for rutabagas before extended storage; it could be harmful. However, they are often hot-waxed with paraffin just before being marketed to improve appearance and prevent undue moisture loss and consequent shriveling. Too heavy a wax coating may cause severe injury from internal breakdown due to suboxidation. (See *355, 675*.)

Rutabagas can stand slight freezing without injury. Severe freezing causes water-soaking and light browning of the flesh, and fermentation. Rough handling of the roots during harvesting and during filling of bins may increase storage losses. The growth regulator maleic hydrazide, applied before harvest, is effective in preventing sprouting in storage.

Prepeeled rutabagas packaged in consumer film bags keep in good condition for 3 weeks at 1°C (*23*).

Salsify

(Temperature, 0°C (32°F); relative humidity, 95 to 98 percent)

Topped salsify has the same storage requirements as topped carrots. High relative humidity is a must, since the long slender roots are highly sensitive to shriveling from moisture loss. Losses from shrivel can be minimized if perforated film crate liners are used (*428*). The roots are not injured by slight freezing, but they should be carefully handled while frozen. Under the conditions specified, they should keep for 2 to 4 months.

Scorzonera or black salsify has similar storage requirements. Extended storage is reported to be possible with storage in a controlled atmosphere of 3 percent oxygen and 3 percent carbon dioxide at 0°C (*925*).

Spinach

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

Spinach is very perishable; hence, it can be stored for only 10 to 14 days. The temperature should be as close to 0°C as possible because spinach deteriorates rapidly at higher temperatures (*720*). Crushed ice should be placed in each

package for rapid cooling and for removing the heat of respiration. Top ice is also beneficial. Hydrocooling and vacuum cooling are other satisfactory cooling methods for spinach.

Most spinach for fresh market is prepackaged in perforated plastic bags to reduce moisture loss and physical injury. Controlled atmospheres with 10 to 40 percent carbon dioxide and 10 percent oxygen have been found to be beneficial in retarding yellowing and maintaining quality (*131, 653*).

Squashes

See "Pumpkins and Squashes."

Sweetpotatoes

(Temperature, 13° to 16°C (55° to 60°F), see text; relative humidity, 85 to 90 percent)

Sweetpotatoes are usually stored in nonrefrigerated commercial or farm warehouses. The primary purpose of storing is to permit orderly marketing during several months after harvesting. Sweetpotatoes should first be cured by holding at 29°C (85°F) and 90 to 95 percent relative humidity for 4 to 7 days (*492, 552*). Curing helps prevent the entrance of decay organisms by healing cuts and other injuries received in harvesting and handling. Such injuries should be kept to a minimum by careful handling. If the curing temperature and relative humidity are lower than recommended, healing is slower and less effective in preventing subsequent decay in storage or marketing (*487, 552*). Usually, sweetpotatoes will not keep satisfactorily if they have been exposed to excessively wet soil conditions just before harvest; chilled before or after harvest by exposure to temperatures of 10° or below for about a week; or subjected, upon harvest, to a delay of 2 or more days before being provided with optimum conditions for healing (*171, 488, 1047*). Prompt curing after harvest is stressed, but it is especially important for sweetpotatoes that are harvested during or after a period of cold weather. Enough ventilation should be provided during curing to prevent accumulation of carbon dioxide, depletion of oxygen, or condensation of moisture.

After curing, the temperature should be reduced to 13° to 16°C, usually by ventilating the storage with outside air (*170, 492*). The relative humidity should remain at 85 to 90 percent during storage. Most cured cultivars will keep satisfactorily for 4 to 7 months under these conditions. Storage at relative humidities above 90 percent is not recommended because of the possible development of surface discoloration and surface mold on the roots. Weight loss can be expected to be 2 to 6 percent during curing and about 2 percent a month during subsequent storage (*492*). Transformation of starch to sugar in sweetpotatoes takes place during curing and continues in storage for approximately 5 months.

The sweetpotato is of tropical origin and is chilled if held at temperatures below about 12°C. Uncured roots are more susceptible to chilling than cured ones. Cultivars differ slightly in their ability to withstand chilling injury, but all cultivars are sufficiently susceptible to make it desirable to avoid chilling conditions. Short periods at temperatures as low as 10° need not cause alarm; but after a few days at 10°, or shorter periods at temperatures below this, sweetpotatoes may develop discoloration of the flesh, internal breakdown, off-flavors and hard core when cooked, and increased susceptibility to decay (*170, 550*).

Temperatures above 16°C stimulate development of sprouts (especially at high humidities), pithiness, and internal cork (a symptom of a virus disease) when it is present (*490, 492*).

Refrigeration is now used in some large sweetpotato storages to extend the marketing season into warm weather, when ventilation will not maintain low enough temperatures.

Sweetpotatoes are usually stored in bulk bins or slatted crates. Palletization of crates and use of pallet boxes facilitate handling. Some of the newer storages equipped for palletized handling have separate curing and storage rooms. Sweetpotatoes can be cured in palletized field boxes in a room designed to provide recommended conditions for curing, and after curing, the sweetpotatoes can be carefully moved with a forklift to a room in which storage conditions are maintained continuously (*491, 492, 1047*).

Curing and storage rooms must be kept clean. If storage containers are reused, they should be steam heated to 50°C for 6 hours before use to reduce black rot and scurf contamination.

Sweetpotatoes are usually washed and graded, and sometimes waxed, before being shipped to market. They should be treated with a fungicide to reduce decay during marketing (*1047*). An effective fungicide is 2,6-dichloro-4-nitroaniline (Botran).

Consumer packaging of sweetpotatoes in film bags or overwrapped trays is done mainly to aid marketing and should not be done prior to storage. The shelf life of washed and fungicide-treated roots in consumer packs is only 2 to 3 weeks. Weight loss of roots during marketing is much less in perforated film bags than in mesh bags. Perforation of 1.4- to 2.3-kg (3- to 5-lb) polyethylene bags with about thirty-two 6-mm (1/4-in) holes is essential to lower the internal relative humidity and avoid excessive sprouting, rooting, and dampness (*489*).

Controlled-atmosphere storage of sweetpotatoes is not a commercial practice, and the feasibility of long-term storage in CA remains unclear (*149*). Research showed that roots stored in 2 to 3 percent carbon dioxide and 7 percent oxygen were better than check roots held in air, as indicated by lower total losses due to decay and weight loss (*596*). However, sweetpotatoes stored at above 10 percent carbon dioxide or below 7 percent oxygen often developed an alcoholic flavor or other off-flavor.

Rhizopus soft rot is the most important and rapid developing

storage and transit rot. For information on this and other sweetpotato storage diseases see *748, 1047.*

Tamarillos

(Temperature, 3° to 4°C (37° to 40°F); relative humidity, 85 to 95 percent)

Tamarillos, or tree tomatoes, are best stored at 3° to 4°C (*349*). At temperatures lower than 3°, they are subject to chilling injury, which is mainifested by surface pitting and discoloration. Storage for 10 weeks is possible. Tamarillos are high in anthocyanin and acids (*382*). A ripening period may be required before they become pleasant to eat. Ethylene gas may be used to accelerate the maturation and ripening of the fruit (*739*). A postharvest hot-water treatment is helpful in reducing fungal rots (*349*).

Taro (Dasheens)

(Temperature, 7° to 10°C (45° to 50°F); relative humidity, 85 to 90 percent)

This tropical edible corm has a higher starch content than either potatoes or sweetpotatoes. It should keep 4 to 5 months at 7° to 10°C if harvested and handled carefully. It does not require the high-temperature curing given sweetpotatoes. Good air circulation is desirable (*119*).

Tomatoes

(Temperature: mature-green, 13° to 21°C (55° to 70°F); ripe, 7 to 10° (45° to 50°F). Relative humidity, 90 to 95 percent)

Tomatoes are chilling sensitive, so the recommended storage temperature differs with maturity of the fruit. Temperature management is critical to maintain quality.

Mature-green tomatoes cannot be successfully stored at temperatures that greatly delay ripening. Tomatoes held for 2 weeks or longer at 13°C may develop an abnormal amount of decay and may fail to develop a deep red color. The optimum temperatures for ripening mature-green tomatoes range from 18° to 21°. Tomatoes will not ripen normally at temperatures above 27°. A temperature range of 14° to 16° is probably most desirable for slowing ripening without increasing decay problems. At these temperatures the more mature fruit within the mature-green range will ripen enough to be packaged for retailing in 7 to 14 days.

Fruit held below 10°C become susceptible to alternaria decay during subsequent ripening (*608*). Increased decay during ripening occurs after 6 days' exposure at 0° or 9 days at 5° (*609*). Mature-green tomatoes may also be damaged by low temperatures in the field. A high percentage of tomatoes exposed to temperatures below 10° for a week before harvest would probably develop alternaria rot even at recommended storage temperatures (*602*). Some loss due to chilling can be expected in northern-California fall-grown tomatoes exposed for over 95 hours to temperatures below 16° during the week before harvest. Severity of chilling increases with increases in exposure time, so 135 hours' exposure to below 16° may result in heavy losses (*641, 644*).

Chilling periods for fruit while in the field, during transit, and in storage have a cumulative effect. Thus, fruit chilled for only a short period in the field can become very susceptible to decay when held for only a short period at chilling temperature during transit or storage. Tomatoes should be kept out of cold, wet rooms because in addition to potential development of chilling injury, extended refrigeration damages the ability of fruit to develop desirable fresh tomato flavor.

Ripening of tomatoes is initiated by the ethylene they produce (*385, 740*). However, in commercial practice, mature-green tomatoes are commonly treated with supplemental ethylene to hasten ripening and provide for uniform ripening within a lot. For treatment, tomatoes are exposed to 100 to 150 p/m ethylene for 24 to 48 hours at 20° to 25°C and 85 to 90 percent relative humidity (*308*). Ethylene is applied in a fairly airtight room by a shot method, a generator, or a flow-through system (*308*). Immature tomatoes may ripen with supplemental ethylene, but the ripened fruit will lack quality (*557, 1057*). Fruit beyond the breaker stage do not benefit from supplemental ethylene because their ripening processes already have been initiated by their own ethylene (*745, 1057*).

Light red tomatoes with 60 to 90 percent red color can be held up to a week at 10°C. If held longer, they will probably not have a normal shelf life during retailing. Riper tomatoes will tolerate lower temperatures (*611*). For example, **firm-ripe** tomatoes can be held a few days at 7° to 10°. Long holding of ripened tomatoes at low temperatures (5° or below) results in loss of color, shelf life, and firmness (*315, 1070*).

When it is necessary to hold firm-ripe tomatoes for the longest possible time before their immediate consumption upon removal from storage, as for example, for shipboard or overseas use, they can be held at 0° to 1.5°C for up to 3 weeks (*696*). Such tomatoes, although acceptable, would not be of high quality and would have little if any shelf life remaining. Mature-green, turning, or pink tomatoes should be ripened before storing at such low temperatures.

A storage temperature of 10° to 13°C is recommended for pink-red to firm-red **greenhouse-grown** tomatoes. Ripening of less mature tomatoes at 21° is recommended before storage at 10° to 13° (*21*).

Research showed that an atmosphere with 3 percent oxygen and 97 percent nitrogen extended the life of mature-green tomatoes up to 6 weeks at 13°C and that the flavor of the ripened fruit had no off-flavor and was acceptable to the taste panel (*691*). A 1-percent-or-lower oxygen level can cause off-flavor. Increased carbon dioxide levels provide no benefit; in fact, levels of 3 to 5 percent have been reported to cause injury at 13°.

(See also *228, 395, 606, 789, 964.*)

Turnips and Turnip Greens

(Temperature, 0°C (32°F); relative humidity, 95 percent)

Topped turnips require storage conditions similar to those for topped carrots. Turnips in good condition can be expected to keep 4 to 5 months at 0°C and high relative humidity. At higher temperatures (5° and above) decay will develop much more rapidly than at 0°. Injured or bruised turnips should not be stored. Turnips should be stored in slatted crates or bins, and good air circulation around containers should be provided.

Packaging turnips in perforated plastic bags helps keep the humidity high around the roots during marketing and reduces shriveling.

Dipping turnips in hot melted paraffin wax gives a glossy appearance and is of some value in reducing moisture loss during handling. However, waxing is primarily to aid in marketing and is not recommended before long-term storage (*254*).

Turnip greens are usually stored only for a short period. They should keep about as well as spinach at 0°C with crushed ice in packages.

Waterchestnuts

(Temperature, 0° to 2°C (32° to 36°F); relative humidity, 98 to 100 percent)

Waterchestnuts can be stored at least 10 months at 0°C and 8 months at 5° if the corms are submerged in sodium hypochlorite solution soon after harvest. The initial concentration of about 1,000 p/m (0.1 percent) dwindles to essentially zero within 3 to 5 days. Anaerobiosis was not a problem when 23-kg (50-lb) lots were stored in open containers with the solution 60 cm (2 ft) deep. With the standard method of storage and packing waterchestnuts in moist sphagnum moss, storage life is limited to 1 to 2 months between 0° and 5° if mold growth is to be essentially absent, and to 2 to 4 months if a 50 percent mold incidence is acceptable (*454, 789*).

Watercress

(Temperature, 0°C (32°F); relative humidity, 95 to 100 percent)

The high perishability of watercress makes prompt handling and refrigeration imperative. The leaves of watercress wilt and become yellow and slimy when improperly handled. Watercress should be precooled promptly after harvest, either by hydrocooling or vacuum cooling, and stored at 0°C with high relative humidity. It is bunched and usually packed in alternate layers with flake ice. Watercress stored at 0° in waxed cartons with top ice holds up well for 2 to 3 weeks (*417*). A similar storage life is possible by using perforated polyethylene crate liners and package icing to minimize wilting. Naked bunches of watercress are highly perishable even at 0° and may keep only 3 or 4 days (*858*). In watercress, a 15-percent weight loss will cause only a trace of wilting, and a 40-percent weight loss will cause moderate wilting (*417*).

Yams

(Temperature, 16°C (61°F); relative humidity, 70 to 80 percent, see text)

Yams are a tropical tuber crop (*Dioscorea* spp.) produced mainly in the Caribbean area, west Africa, and southeast Asia. Yams are botanically and gustatorially distinct from the moist-type sweetpotato roots that in the United States are often called yams.

Storage at 16°C with 70 to 80 percent relative humidity and adequate ventilation is recommended for storage of cured yams. Curing is accomplished after harvest by holding the tubers at 29° to 32° (84° to 90°F) with 90 to 95 percent relative humidity for 4 to 8 days (*74, 278*). Curing allows suberization of surface injuries and reduces weight loss and rotting in storage. This curing can be accomplished either in a controlled room or under tropical ambient conditions (*278*). Properly cured yams should keep 6 to 7 months at 16°. If this temperature cannot be maintained, then 30° is preferable to intermediate temperatures and storage for 3 to 4 months is possible (*789*). Cured yams keep longer than noncured ones.

Yams are chilling sensitive and will be injured at 12°C and below. Low-temperature injury has been observed after 5 weeks at 5° or 7°, 3 weeks at 3°, and 5 days at 2° (*179, 278*). When chilled, tissues discolor, soften with a waterlogged consistency, and eventually decay.

For information on market and storage diseases see *676*. (See also *769*.)

Dried Fruits and Vegetables

The moisture in dried fruits may range from 25 percent to as low as 2 percent, and that in vegetables from 7 percent to a low of 0.3 percent. Dried fruits and vegetables are subject to darkening, browning, loss in flavor, loss in vitamin content, insect damage and mold; all these effects are retarded by low-temperature storage. Raisins, figs, and prunes are also subject to sugaring on the surface or within the flesh. Dried cut fruits are treated with sulfur dioxide to prevent darkening and attack by micro-organisms. Sulfur dioxide is soon lost at high temperatures, and the loss may allow more rapid deterioration.

Packaging in moisture-retentive materials such as foil or film aids in protecting dried fruit from excessive drying when they are exposed to too low humidity or too high temperature. Dried vegetables are generally packed in airtight containers, often with an inert gas such as nitrogen, or in vacuum. Antioxidants and desiccants may also be included. Temperature is less critical with dried or dehydrated vegetables, as they contain less moisture than dried fruits. Most dried vegetables should keep several months to a year at 20°C. Cold storage (7° or lower), considered necessary only for long storage periods, helps dried vegetables to retain initial flavor, vitamins, and natural color and to retard insect activity.

Refrigeration is beneficial in augmenting drying as a means of preserving fruits. The optimum conditions for holding most dried fruit are 55 to 60 percent relative humidity and a temperature of 0° to 4°C. Except in regard to insect control, low humidity is more important than low temperature for storage of dried fruit. Refrigerated storage at 0° to 4° retards and controls insect infestation. Dried apricots, raisins, figs, prunes, apples, pears, peaches, and dry-texture dates, for example, Deglet Noor, should keep in good condition 1 year or possibly longer at 0° to 4° (*33, 68, 794*). They keep only about 3 months at 15°. Deglet Noor dates should be cured at about 35° (95°F) to hasten maturation before cold storage (*789*). Soft, invert sugar dates will darken rapidly at 0° and often develop sugar spots. If stored frozen at −18°, soft dates will remain in good condition for a year (*794*).

Small differences in moisture content have a profound effect on the keeping quality of dry-texture Deglet Noor dates. In 24° storage, fruit of this cultivar darken four times as rapidly at 24 percent moisture content as they do at 20 percent moisture. At lower temperatures the difference is less striking but favors the lower moisture dates (*798*). Sugaring is prevented in raisins for 1 year at the recommended storage temperature and humidity, provided the moisture content is not unusually high. Raisins contain 15 to 20 percent moisture, and for extremely long storage the lowest possible moisture content should be maintained (*33, 677, 911*). Several of the dried fruits will tolerate moderately higher relative humidity (70 to 80 percent) than the recommended 55 to 60 percent, but the storage life may be only 4 to 6 months because of moisture pickup and molding (*792*).

Dried jujubes (Chinese dates) at 20 to 25 percent moisture can be stored up to a year at 0° to 20°C with a relative humidity of 50 to 65 percent (*447*).

Frozen Fruits, Vegetables, and Fruit Juice Concentrates

Most frozen fruits, vegetables, and juices can be stored for about a year at −18°C (0°F) or lower. At −18° growth of microbes is stopped and the chemical changes which cause loss of quality are slowed down. Frozen foods are not inert, however, and are sensitive to temperature. As storage temperature rises from −18° to −15° and above, frozen foods lose quality at a faster and faster rate. The following combinations of storage duration (time) and temperature are equivalent in their effect on the quality of sensitive fruits and vegetables: 1 year at −18°, 5 months at −15°, 6 weeks at −12°, and 3 weeks at −9° (*427, 942*). The degree to which individual products tolerate the time-temperature effects gives rise to an abbreviated term, "time-temperature tolerance," or TTT, to describe frozen foods. Peaches may turn brown in 2 or 3 months at −12°; strawberries will undergo flavor changes in 3 months at this temperature. Green color in peas and green beans is retained fairly well for 1 year at −18° but for only about 3 months at −12°.

Storage at −18°C or below is essential for frozen orange juice concentrate and is recommended strongly for all juice concentrates to preserve fresh flavor (*33*). Flavor loss is negligible during storage at −18° for a year or more but is appreciable even at slightly higher temperatures.

Frozen foods lose quality when exposed to high temperature, and the loss in quality is not corrected by return of the foods to −18°C. A brief exposure, such as a few days at −12°, will not cause significant quality losses, but long or frequent exposures to temperatures above −18° are harmful. For this reason it is important that the temperature of foods prepared for freezing be lowered to −18° promptly and that the temperature be maintained at or below this level throughout the marketing period, including storage, transit, wholesaling, and retailing, and during storage by the user (*110*).

The use of moisture-retentive materials for packaging is essential

for long storage to avoid moisture loss resulting in "freezerburn."

Air circulation should be moderate. It should be no more than necessary to provide uniform temperatures to keep desiccation at a minimum. Temperature fluctuations should be avoided. However, small fluctuations are normal and almost unavoidable (*942*). Relative humidity should be high.

Frozen foods should never be stored in contact with floors or walls of storage rooms. At least 8 cm (3 in) from floors (by the use of floor racks) and 10 to 30 cm (4 to 12 in) from outside walls are recommended. Sufficient storage space should be available so that new frozen food can be stored immediately in its proper location and correct rotation order. First in should be first out! (See also *196.)*

Chilled Citrus Juices and Citrus Fruit Salads

(Temperature, −1° to 0°C (30° to 32°F))

Chilled citrus juices are usually single strength. There are two types of chilled juice: (1) thermally processed (pasteurized) and (2) aseptically packed. The latter is a product that is quick chilled, processed with a minimum of heat, and packaged with chemical sterilants. Refrigeration is essential for both types to retain a pleasing flavor and retard ascorbic acid loss. Citrus juices are heat processed to kill bacteria and avoid fermentation of the product, and to inactivate enzymes, which cause the "juice cloud" to settle out and result in an unattractive product. Chilled juices retain high quality longest if stored near −1°C. However, they should remain stable without fermentation for up to 3 months at 4° (*699, 785, 942*). Freshly squeezed orange juice packaged without heat processing will keep only 1 or 2 weeks at −1° to 2°. Canned single-strength citrus juices have a shelf life of 1 year at 4° to 10°.

Citrus fruit salads are packed in sucrose syrup. For maximum storage life, they should be stored at about −2°C. Shelf life of citrus salads is about 12 weeks at −2° to −1°, 5 to 6 weeks at 4°, and less than 1 week at 10° (*784*). (See also *655, 665.*)

Nuts (Including Peanuts)

Nuts are less perishable than most fruits and vegetables, but refrigerated storage is used rather extensively to maintain optimum quality for extended periods. Nuts are subject to various forms of deterioration, such as loss of texture, color, and flavor; development of staleness, rancidity, and molding; and insect damage. Refrigerated storage retards or prevents all these types of deterioration.

The approximate storage life of various kinds of nuts at several temperatures is given in table 14. Nuts in the shell usually remain in good condition much longer than the shelled nuts. Chestnuts, pecans, and walnuts are more perishable than most other nuts. Chestnuts are very susceptible to mold growth, and many are infected when harvested. Only chestnuts relatively free of mold or decay should be stored, and they should be placed in cold storage immediately after harvest. Pecans and walnuts should be placed in cold storage within a month or two after harvest. Most other nuts can be safely stored in unrefrigerated warehouses during the cool months of the winter, but they should be placed in refrigerated storage before the weather turns warm in the spring. Pistachio nuts are very stable. Shelled pistachios have been held over a year at 24°C

Table 14
Approximate storage life of nuts at various temperatures

		Months in shell at—			Months without shell at—			Years in vacuum pack[1]	Years frozen[1]
Kind of nut	Literature reference	0°C (32°F)	10°C (50°F)	21°C (70°F)	0°C (32°F)	10°C (50°F)	21°C (70°F)	0° – 4.5°C (32° – 40°F)	−18°C (0°F)
Almonds	*1067*	15-20	6-12	6	6-12	6	6	1-2	1 or more
Brazil	*428*	8-12	—	—	—	—	—	1	1 or more
Cashews	*942*	—	—	—	12	—	—	1-2	1 or more
Chestnuts	*515, 966*	[2]4-6	—	—	12	—	—	1	1-2
Filberts	*143, 1067*	15-30	15-30	12	6-10	6	2-3	1	1-2
Macadamia	*942, 1022*	12-24	12-24	—	15-20	3-6	1-3	1	1-2
Peanuts	*947, 1052*	24	9	6	12	6	—	1-2	3
Pecans	*116, 1067*	12-18	6	2	5-12	4-6	1	1-2	1-2
Pistachio	*942, 1022*	12	12	—	12-24	15	15	1-2	3
Persian Walnuts	*1067*	10-20	6-12	2-4	6-12	6	1	1-3	1-2
Black walnuts	*1067*	—	—	—	15	8	8	—	—

[1] Data from "Commodity Storage Manual" of the Refrigeration Research Foundation (*942*).
[2] In protective packages.

(*1022*). Longer storage life can be expected for nuts kept in vacuum packs under refrigerated conditions, as shown in table 14.

Most nuts withstand freezing and can be stored several years at −18°C. However, it is not the normal practice to freeze nuts and nutmeats to preserve their quality. Unhusked chestnuts are stored commercially at freezing temperatures in France (*988*). Freezing of shelled kernels of chestnuts blanched 1 or 2 minutes in boiling water has also been suggested (*966*). Noncured peanuts are damaged by freezing temperatures (*1020*), but peanuts with a moisture content suitable for storing are not. Such peanuts have been kept experimentally for several years at −18° (*947*). Pecans have been held 2 years at −15° (*116*).

Nuts (except chestnuts) require a fairly low (60 to 75 percent) relative humidity. If it is too low, there is undue drying; if it is too high, mold growth, rancidity, and other quality losses may occur. A relative humidity of 65 to 70 percent is recommended for shelled pecans; and one of 65 to 75 percent, for unshelled pecans to prevent excessive drying (*1054*). A relative humidity of 60 to 70 percent is recommended for peanuts (*947*). For filberts 60 to 65 percent is recommended (*143*). Almonds should be stored at 60 to 75 percent and Persian walnuts at 65 percent relative humidity. Chestnuts dry out and become hard and bony even at fairly high humidity; hence, protective packaging is needed for them.

All nuts are dried after harvest, as they contain 25 to 50 percent moisture by weight.

A moisture content of less than 3.5 percent is suggested for pecan and walnut kernels for good storage (*1022*) and less than 8 percent for filberts (*143*). The moisture content of pecans should be reduced to 4.5 percent within about 2 weeks after harvest to retard deterioration (*1054*). The moisture content of peanuts is usually reduced to below 10 percent; a moisture content of 6 to 7 percent seems to be optimum (*947*). With this low moisture content, it is difficult for molds to grow.

Packaging is not critical for storing nuts in the shell, but in shelled nuts the free oil "crawls" onto cartons. For this reason an impermeable box liner such as plastic, glassine, or metal foil is recommended (*33*). Some types of polyethylene and Pliofilm may impart an undesirable odor to nuts (*33*). Drying out of chestnuts can be prevented by the use of loosely fitting friction-top cans or perforated (or loosely fastened) polyethylene-lined boxes (*515, 966*).

Shelled nuts can be expected to keep only about half as long as nuts in the shell. However, the savings in space and weight generally make it desirable to store nuts in the shelled state. Broken pieces are more perishable than halves or whole kernels.

The shelf life of shelled nuts can be lengthened by vacuum packing (*1054, 1067*), freezing, or storage in nitrogen (*1022*). Treatment with antioxidants also extends the shelf life of shelled nuts packaged in transparent film packages (*1022*).

Nuts should not be stored with foods having pronounced odors, for example, fresh fruits, smoked meat, onions, or potatoes. It is probably safest to store nuts in a separate room. Pecans are especially susceptible to ammonia injury, which causes severe discoloration of the kernels (see p. 27). Peanuts also are easily damaged by ammonia (*1052*).

Peanuts for processing are commonly shelled in the fall and placed in storage at a temperature near 0°C and 60 to 70 percent relative humidity. Air circulation throughout the room is desirable. Peanuts for roasting in the shell are often placed in cold storage.

Storage at 7°C or below will control insect infestation in nuts. Infestation by insects in farmers' stock peanuts held in common storage can be prevented by sanitation, residual sprays, and fumigation with an approved fumigant (*965*). (See also *142, 790, 1053.*)

The recommended storage temperature and approximate storage life for cut flowers and florist greens are listed in table 15. Further details for some flowers are given in the text. Much additional research is needed to determine the storage requirements for all flowers. Data for some flowers in the table have been carefully determined through experimentation; other recommendations are based on commercial practice and will need revision as research progresses. The volume of floral crops placed in storage is very minor compared to that of fruit and vegetables placed in storage.

Marketing Cut Flowers

It is estimated that there is a 20-percent loss of cut flowers during marketing (*909*). Losses occur during harvest, handling, storage, transportation, wholesaling and retailing. These losses are excessive and can be reduced by greater attention to careful handling, better temperature management, sanitation, and use of preservatives.

In the storage of cut flowers, at least four viewpoints should be considered—those of the grower, the wholesaler, the retailer, and the consumer.

Many growers have one or more storage rooms, held at 1° to 4°C, for holding cut blooms in good condition until enough stock has accumulated to warrant shipment. As a rule, this would not take more than 24 hours. Growers interested in long-term storage should have a separate room kept at the optimum temperature for each particular crop. For maximum long-term storage, flowers should be dry-packed and held at −0.5° to 0°.

The wholesale florist is not interested in storing flowers and usually can replenish flower stocks daily or within a few days. Wholesalers often have two or more refrigerated rooms set at 0.5° to 2° and at 4°C. Most flowers are best stored at 0.5° to 2° rather than at higher temperatures. A room maintained at 7° to 10° may be needed for holding tropical or cold-sensitive flowers (for example, orchids, anthurium).

Table 15
Storage recommendations for cut flowers, florist greens, bulbs, cuttings, and miscellaneous nursery stock

Commodity	Storage temperature °C	Storage temperature °F	Approximate storage period[1]	Highest freezing point[2] (°C)	Literature references
Cut flowers[3]					
Acacia	4	40	3-4 days	-3.5	*554, 891*
Alstroemeria	4	40	2-3 days	—	*141*
Allium	0-2	32-35	2 weeks	—	*190*
Anemone	4-7	40-45	2 days	-2.1	*891*
Anthurium[4]	13	56	2-4 weeks	—	*16, 452, 891, 909*
Aster, China	0-4	32-40	1-3 weeks	-.9	*141, 472, 891*
Bird-of-paradise	7-8	45-46	1-3 weeks	—	*312*
Bouvardia	0-2	32-35	1 week	—	*554, 891*
Buddleia	4	40	1-2 days	—	
Calendula	4	40	3-6 days	—	*141, 554*
Calla	4	40	1 week	—	*554*
Camellia[5]	7	45	3-6 days	-.7	*554*
Candytuft	4	40	3 days	—	*891*
Carnation[6]	-0.5-0	31-32	3-4 weeks	-.7	*246, 657, 730, 892*
Carnation buds	-0.5-0	31-32	4-12 weeks	-.7	*286, 345, 473, 909*
Carnation, miniature	-0.5-0	31-32	2 weeks	—	*891*
Chrysanthemum	-0.5-0	31-32	3-4 weeks	-.8	*246, 477, 891, 909*
Clarkia	4	40	3 days	—	
Columbine	4	40	2 days	-.5	
Coreopsis	4	40	3-4 days	—	
Cornflower	4	40	3 days	-.6	*554, 891*
Cosmos	4	40	3-4 days	—	*554*
Crocus	0.5-2	33-36	1-2 weeks	—	
Dahlia	4	40	3-5 days	—	*1*
Daisy, English	4	40	3 days	—	*891*
Daisy, Marguerite	2	36	1-2 weeks	—	*136, 891*
Daisy, Shasta	4	40	7-8 days	-1.1	*554, 891*
Delphinium	4	40	1-2 days	-1.6	*891*
Eucharis[5]	7-10	45-50	7-10 days	—	
Feverfew	4	40	3 days	-.6	
Forget-me-not	4	40	1-2 days	—	
Foxglove	4	40	1-2 days	—	
Freesia[6]	0-0.5	32-33	10-14 days	—	*141, 891*
Gaillardia	4	40	3 days	—	
Gardenia[5]	0-1	32-34	2 weeks	-.6	*246, 730, 891*
Gerbera	1-4	34-40	1-2 weeks	—	*141, 891, 909*
Ginger	13	55	4-7 days	—	*1039*
Gladiolus[6]	2-5	35-42	5-8 days	-.3	*284, 475, 891, 909, 1014*
Gloriosa	4-7	40-45	4-7 days	—	
Godetia	10	50	1 week	—	
Gypsophila	4	40	1-3 weeks	—	*141, 582, 891*
Heather	4	40	1-3 weeks	-1.8	*554, 891*
Heliconia	12	54	10 days	—	*1039*
Hyacinth[6]	0-0.5	32-33	2 weeks	-.3	*554, 891*

See footnotes at end of table.

Table 15
Storage recommendations for cut flowers, florist greens, bulbs, cuttings, and miscellaneous nursery stock—Continued

Commodity	Storage temperature °C	Storage temperature °F	Approximate storage period[1]	Highest freezing point[2] (°C)	Literature references
Iris, bulbous	−0.5-0	31-32	1-2 weeks	−.8	*288, 439, 730, 891*
Laceflower	4	40	3 days	—	
Lilac, forced	4	40	4-6 days	—	
Lily	0-1	32-34	2-3 weeks	−.5	*246, 891*
Lily-of-the-valley[6]	−0.5-0	31-32	2-3 weeks	—	*246, 730*
Lupine	4	40	3 days	—	
Marigolds	4	40	1-2 weeks	—	*659*
Mignonette	4	40	3-5 days	—	
Narcissus[6]	0-0.5	32-33	1-3 weeks	−.1	*673, 692, 730, 909*
Orchid, cattleya[4, 5]	7-10	45-50	2 weeks	−.3	*730, 829, 891, 909*
Orchid, cymbidium	−0.5-4	31-40	2 weeks	—	*829, 909*
Orchid, vanda	13	55	5 days	—	*514, 909*
Ornithogalum	4	40	4-6 weeks	—	*275*
Poppy	4	40	3-5 days	—	
Peony, tight buds	0-1	32-34	2-6 weeks	−1.1	*404, 680, 730*
Phlox	4	40	1-3 days	—	
Poinsettia	10-15	50-60	4-7 days	−1.1	*910*
Primrose	4	40	1-2 days	—	
Protea	4	40	7-10 days	—	*891*
Ranunculus	0-5	32-41	7-10 days	−1.7	*656, 891*
Rose (in preservative)[6]	0.5-2	33-35	4-5 days	−.5	*482, 891, 893, 909*
Rose (dry pack)[6]	−0.5-0	31-32	2 weeks	−.5	*246, 590, 658, 891*
Snapdragon	4	40	1-2 weeks	−.9	*753, 758, 891, 940*
Snowdrop	4	40	2-4 days	—	
Squill	0-0.5	32-33	2 weeks	—	
Statice[6]	2-4	35-40	3-4 weeks	—	*554, 891*
Stephanotis[5]	4	40	1 week	—	*554, 891*
Stevia	4	40	3 days	—	
Stock	4	40	3-5 days	−.4	*141, 496, 891, 909*
Strawflower, fresh[6]	2-4	35-40	3-4 weeks	—	*891*
Sweet pea	−0.5-0	31-32	2 weeks	−.9	*730*
Sweet-william	7	45	3-4 days	—	
Tulip[6]	−0.5-0	31-32	2-3 weeks	—	*125, 667, 990, 1032*
Violet	1-5	34-41	3-7 days	−1.8	*554*
Zinnia	4	40	5-7 days	—	*554, 891*
Florist greens (decorative foliage)[3, 7]					
Adiantum (maidenhair)	0-4	32-40	—	—	
Asparagus (plumosa)[8]	2-4	35-40	2-3 weeks	−3.3	*891*
Asparagus (sprenger)[8]	2-4	35-40	2-3 weeks	—	*891*
Buxus (boxwood)	2-4	35-40	—	—	*891*
Camellia	4	40	—	—	*891*
Cedar[8]	0	32	—	—	
Chamaedorea	7	45	2-3 weeks	—	*891*

See footnotes at end of table.

Table 15
Storage recommendations for cut flowers, florist greens, bulbs, cuttings, and miscellaneous nursery stock—Continued

Commodity	Storage temperature °C	Storage temperature °F	Approximate storage period[1]	Highest freezing point[2] (°C)	Literature references
Florist greens (decorative foliage)[3, 7]—Continued					
Cordyline (ti)	7-10	45-50	2-3 weeks	—	*891*
Croton	2-4	35-40	—	—	
Dieffenbachia	13	55	—	—	
Dracaena	2-4	35-40	—	-1.6	
Dagger & wood ferns[8]	0	32	2-3 months	-1.7	
Eucalyptus	2-4	35-40	1-3 weeks	-1.8	*891*
Galax[8]	0	32	—	—	
Ground pine[8]	0	32	—	—	
Hedera	2-4	35-40	2-3 weeks	-1.2	*891*
Ilex (holly)[6, 8]	0-4	32-40	3-5 weeks	-2.8	*263, 624, 1071*
Juniper	0	32	1-2 months	—	
Leatherleaf (baker fern)	1-4	34-40	1-2 months	—	*891, 912*
Leucothoe, drooping	2-4	35-40	—	—	
Magnolia	2-4	35-40	2-4 weeks	-2.8	
Mistletoe[6]	0	32	3-4 weeks	-3.9	*850*
Mountain-laurel	0	32	2-4 weeks	-2.5	
Myrtus (myrtle)	2-4	35-40	—	—	*891*
Palm	7	45	—	—	
Philodendron	2-4	35-40	—	—	
Pittosporum	2-4	35-40	2-3 weeks	—	*891*
Podocarpus	7	45	—	-2.3	*891*
Pothos	2-4	35-40	—	—	
Rhododendron	0	32	2-4 weeks	-2.5	
Salal (lemon leaf)[8]	0	32	2-3 weeks	-2.9	*891*
Scotch-broom	4	40	2-3 weeks	—	*891*
Smilax, southern[8]	4	40	—	—	
Staghorn fern	13	55	—	—	
Vaccinium (huckleberry)[8]	0	32	1-4 weeks	-3.0	*891*
Woodwardia fern	0-4	32-40	—	—	
Bulbs, corms, rhizomes, tubers, and roots[9]					
Achimenes	7-10	45-50	—	—	*123*
Acidanthera	7-13	45-55	—	—	*123, 181*
Allium giganteum	23-25	73-77	—	—	*191*
Alstroemeria	4-10	40-50	—	—	*181*
Anemone coronaria	7-13	45-55	3-4 months	—	*123, 191*
Begonia, tuberous	2-7	35-45	3-5 months	-.5	*191, 560*
Bletilla orchid	2-4	35-40	—	—	
Brodiaea laxa	20-25	68-77	—	—	*191*
Camassia	17-20	63-68	—	—	*191*
Caladium	21	70	—	-1.3	*578*
Canna	4-10	40-50	—	—	*123*
Chionodoxa	20	68	—	—	*191*
Colchicum	17	63	—	—	*191*
Convallaria	-4 to -1	25-30	1 year	—	*191*
Crocus	17	63	2-3 months	—	*191*
Cypella herbertii	4-10	40-50	—	—	*123*
Dahlia	4-9	40-48	5 months	-1.8	*27, 181, 191*
Endymion	17-20	63-68	—	—	*191*
Eranthis	5-9	41-48	—	—	*191*

See footnotes at end of table.

Table 15
Storage recommendations for cut flowers, florist greens, bulbs, cuttings, and miscellaneous nursery stock—Continued

Commodity	Storage temperature °C	Storage temperature °F	Approximate storage period[1]	Highest freezing point[2] (°C)	Literature references
Erythronium	9-17	48-63	—	—	*191*
Freesia	30	86	3-4 months	—	*193, 479*
Fritillaria imperialis	23-25	73-77	—	—	*191*
Fritillaria meleagris	9-13	48-55	—	—	*191*
Galanthus	13-17	55-63	—	—	*191*
Galtonia	7-13	45-55	—	—	*123, 471*
Gladiolus[6]	7-10	45-50	5-8 months	−2.1	*123, 182, 581*
Gloriosa lily	10-17	50-63	3-4 months	—	*123, 181, 261*
Gloxinia	5-10	41-50	5-7 months	−.8	*191, 471*
Hemerocallis	10	50	1 month	—	
Hippeastrum	3-7	38-45	5 months	−.6	*191*
Hyacinthus[6, 10]	17-20	63-68	2-5 months	−1.5	*191, 666, 929*
Hymenocallis	16-21	60-70	—	—	*123, 181, 471*
Iris, Dutch[6]	20-25	68-77	4-12 months	—	*288, 298, 358, 929, 931*
Iris, English	17	63	—	—	*191*
Iris, reticulata	17	63	—	—	*191*
Iris, German	0-5	32-41	—	—	*191*
Ixia	20-25	68-77	—	—	*191*
Ixiolirion	20	68	—	—	*191*
Liatris	0-2	32-35	—	—	*191*
Lilium[6]	−0.5-0.5	31-33	1-10 months	−1.7	*93, 767, 928, 929*
Montbretia	2-5	35-41	—	—	*191*
Muscari[10]	17	63	2-4 months	—	*190, 191*
Narcissus[6]	13-17	55-63	2-4 months	−1.3	*191, 298, 666, 929*
Ornithogalum umbellatum	20	68	—	—	*191*
Ornithogalum thyrsoides	25	77	—	—	*191*
Oxalis adenophylla	17-20	63-68	—	—	*191*
Oxalis deppei	2-5	35-41	—	—	*191*
Peony	0-2	32-35	5 months	—	*191*
Primula	7-10	45-50	—	—	
Puschkinia	16-20	60-68	—	—	*191*
Ranunculus	10-13	50-55	—	—	*181, 191*
Scilla	17-23	63-73	—	—	*191*
Sparaxis	25	77	—	—	*191*
Tigridia	2-5	35-41	—	—	*191*
Trillium	0-2	32-35	—	—	
Tulipa[6]	17	63	2-6 months	−2.4	*191, 666, 929, 930*
Watsonia	4-7	40-45	—	—	*471*
Zantedeschia	4-13	40-55	—	−2.5	*191, 471*
Zephyranthes	4-7	40-45	—	—	*123*
Cuttings and scions[11]					
Azalea, unrooted	−0.5-4	31-40	4-10 weeks	—	*742*
Blueberry wood, unrooted	−1.0	30	5 months	—	*831, 1063*
Carnation, rooted and unrooted.	−0.5-0	31-32	5-6 months	—	*400, 592*
Chrysanthemum, rooted	−0.5-1.6	31-35	3-6 weeks	—	*493*

See footnotes at end of table.

Table 15
Storage recommendations for cut flowers, florist greens, bulbs, cuttings, and miscellaneous nursery stock—Continued

Commodity	Storage temperature °C	Storage temperature °F	Approximate storage period[1]	Highest freezing point[2] (°C)	Literature references
Cuttings and scions[11]—Continued					
Chrysanthemum, unrooted	−0.5-0.5	31-33	5-6 weeks	—	*493*
Geranium, unrooted	−0.5	31	4-6 weeks	—	*230*
Poinsettia, rooted	5	41	1 week	—	*230*
Privet, unrooted	1-2	34-36	6 weeks	—	*230*
Raspberry, unrooted	−1.0	30	12-15 weeks	—	*69*
Rose budwood	−2 to −0.5	28-31	1-2 years	—	
Woody ornamentals and evergreens	0-2	32-36	5-6 months	—	*250, 816*
Nursery stock					
Asparagus rhizomes	−1-0	30-32	3-4 months	—	*1065*
Bedding plants[6]	4-13	40-55	2-4 weeks	—	*267, 663*
Christmas trees	−5-0	22-32	6-7 weeks	—	*617*
Conifer seedlings	0-2	32-36	3-6 months	—	*22, 47, 216*
Herbaceous perennials[11]	−2.8 to −2.2	27-28	4-8 months	—	*566*
Herbaceous perennials[11]	−0.6-1.7	31-35	3-7 months	—	*566*
Rose bushes	−0.5-2	31-36	4-5 months	—	*565, 973*
Seeds[6]	0-10	32-50	1 year	—	*72, 73, 350, 444*
Strawberry plants	−1-0	30-32	8-10 months	—	*1062, 1064*
Tomato plants	10-13	50-55	10 days	—	*626, 637, 766*
Woody ornamentals	0-2	32-36	4-5 months	—	*255, 380, 566, 848*

1 Storage periods given should allow satisfactory handling and keeping after removal from storage. (See *141, 730, 891, 883, 909, 1039.*)
2 Data from Whiteman (*1030*).
3 High relative humidity of 90 to 95 percent recommended in refrigerated storage rooms for cut flowers and florist greens. Likely, some flowers for which temperature of 4°C is recommended could be stored longer and safely at lower temperatures.
4 Stems of orchids and some anthuriums should be placed in vials of water. However, some orchids and anthuriums may be stored by dry-pack methods.
5 Not placed in water for handling or storage but may be misted.
6 See text.
7 At retail level, florist greens held at approximately 4°C for only 1 or 2 weeks. Most stored with stems in water, except where noted otherwise.
8 Usually held in moisture-retentive shipping cases.
9 Desirable relative humidity for storage of most bulbs and related materials is 70 to 90 percent, with adequate ventilation (*190*).
10 Bulbs should be stored in wire-bottom trays, as they may root if stored in paper bags.
11 See tabulation on p.98 and bulletin by Mahlstede and Fletcher (*566*).

The retailer is interested in selling flowers to customers as rapidly as possible. Retailers are not interested in storage for long periods. Most retailers buy the flowers they need for a particular day; a few flowers are stored overnight. Retailers should avoid buying so heavily that their storage facilities are overtaxed, a condition resulting in injury to stored stock by crowding. The retailer usually has at least one display refrigerator and a separate walk-in refrigerated room. A desirable temperature for short-term storage is 4°C. While this temperature is not ideal for many flowers, it is a good compromise. Still, the retail florist should exercise caution when storing cold-sensitive tropical flowers. Two refrigerators are probably the best solution: one set at 1° to 2° and one set at 7° to 10°.

Consumers want flowers that are fresh, have good quality, and last for a reasonable period. Cut flowers should, therefore, be stored for only brief periods to provide customer satisfaction. Cut-flower life depends on proper handling at all levels. Delayed handling, failure to use preservatives, failure to recut stems, or improper refrigeration before final sale may seriously reduce vase life. (See *2, 46, 141, 703, 730, 761, 770, 891, 909, 1039*.)

Causes of Deterioration of Cut Flowers

Flowers deteriorate in many of the same ways as fruits and vegetables through complex physiological processes. There are many reasons why flowers die or become unsalable:

1. **Food depletion** may cause flowers to die. Respiration causes the depletion of stored foods (primarily carbohydrates), and thus its rate often determines the life of flowers. Refrigerated storage is strikingly effective in retarding respiration and, thus, in preserving food supplies (*314, 730, 839*). Stored foods in flowers can be supplemented by floral preservatives.
2. **Attack by bacteria and fungi** shorten flower life. Prompt refrigeration after harvest reduces the risk of postharvest diseases.
3. **Normal maturation and aging** may limit storage and shelf life; therefore, flower maturity at harvest is critical. Some flowers must be harvested at the bud stage to have an adequate market life, for example, roses, gladioli, and snapdragons. Some flowers (for example, larkspur) will shatter as they age.
4. **Wilting** through excessive loss of moisture from transpiration may limit storage and flower longevity. Flowers that have lost 10 to 15 percent or more of their fresh weight are usually wilted. High relative humidity in holding rooms or moistureproof packaging can minimize wilting. The water conducting tissues in flowers held in vases containing water or preservatives can become clogged and restrict water movement. The result is premature wilting. Clogging may be caused by bacteria or may be physiological in nature, as part of normal senescence (*1039*).
5. **Bruising and crushing** will shorten storage life and reduce marketability. Blooms must be handled carefully—not stacked in the arms or on tables like cordwood. Blooms bruised or otherwise damaged from careless handling respire faster and will not last as long as those properly handled.
6. **Improper temperature control** is a major cause of spoilage, particularly when flowers are exposed to warm temperatures for long periods. Holding at temperatures too low may cause deterioration and/or chilling injury in some flowers. Some cultivars of gladioli stored for a week at 0° to 1°C may fail to open properly on removal. Cattleya orchids are severely chilled by 3 to 4 days' storage at −0.5° to 0°, the chilling injury evidenced as discoloration first of the column and then of the sepals and petals.
7. **Color changes** such as fading of carnations and "bluing" of roses will reduce marketability. Again, refrigeration is desirable for preventing color changes and maintaining fresh color.
8. **Accumulation of ethylene** in storage may accelerate the rate of development and aging of many flowers or increase floret shattering (abscission).
9. **Poor quality water,** which includes contaminated water and water with a high mineral salt content, may reduce flower longevity.
10. **Suboptimal cultural practices or conditions,** such as excess fertilization, may be a cause of flowers that deteriorate rapidly. (See *314, 909*.)

Factors Affecting Cut Flower Longevity

Prompt Careful Handling

Most flowers must be handled as highly perishable products. They should be refrigerated promptly after harvest to prevent moisture loss, to remove field heat, and to delay deterioration. Flowers should be moved promptly through marketing channels.

In the United States, some flower storage is absolutely essential for orderly marketing. Although there is less need to store flowers than many fruits and vegetables produced seasonally, there are occasions when flowers can be stored profitably. It should be recognized that some species and cultivars of flowers store better than others. Cut flowers are stored for (1) short intervals, over the weekend, and (2) long periods of 2 to 4 weeks, for a specific future occasion (for example, a holiday). Demand is highest at holidays. Such storage helps growers accumulate flowers for a holiday and reduces the production hazard of uncontrollable elements such as light and temperature (*730*).

Stage of Development

For maximum vase life after storage, most flowers should be cut at the stage that will allow subsequent full floral development and

longevity. Some flowers can be harvested at the tight-bud stage. Buds are easier to handle and are less susceptible to bruising and to such detrimental environmental conditions as high temperature and ethylene. Proper floral maturity is of prime importance. Orchids should be fully developed before harvest. "Bent neck" in roses occurs much more frequently when flowers are cut too immature.

Preharvest growing conditions of nutrition, light intensity, and temperature markedly affect the keeping quality of cut flowers (*591*). The best flowers for storage are normally those that have developed under optimum growing conditions and are free of mechanical or other injuries before harvest. High-quality flowers are "firm" and have "substance," terms that probably could be justified on the basis of higher total-solid-matter content, as contrasted with "soft" blooms that usually develop under conditions of forced growth. Numerous other harvest and keeping quality factors are discussed in *909, 1039*.

Grading and Bunching

Damaged or diseased blooms should be discarded during grading. Diseased flowers may contaminate others. Only high-quality flowers should be stored, for even ideal storage conditions cannot improve initial flower quality. There are no official grades and standards for most cut flowers in the United States.

Flowers should be bunched before they are placed in storage, and tying should be firm but not too tight. If flowers are too tightly crowded in storage, mold growth is favored and rapid cooling is retarded. As a rule, the size of the bunch is determined by custom and does not vary much among markets. Whether 10 or 25 blooms customarily make a bunch probably depended originally on the type of flower. Most of the larger flowers are not bunched but are held in place by cleats in the storage or shipping container. Other factors that determine the size of the handling or sales unit are the cost of the flowers and their inherent susceptibility to mechanical injury. Orchids, camellias, and gardenias need special handling and, therefore, are generally marketed in small units. Some types of flowers can be bunched with no standard bunch size, the size depending on the display quality of the individual flower head or bunch component; such flowers include stevia, gypsophila, statice, and pompon chrysanthemums.

Wrapping the bunches in waxed paper with an opening at the top prevents such species as delphinium and lilies-of-the-valley from tangling during handling. Bunches of roses are customarily wrapped in water-repellent paper. More recently, transparent polyethylene sleeves have been adopted for enclosing bunched flowers and flowering plants to reduce moisture loss, stem breakage, and bruising. Individual net caps may cover the blooms of some of the large kinds of chrysanthemums to prevent tangling.

Flowers should be promptly returned to the cooler after grading and bunching.

Storage Temperature

Low temperature is the chief environmental factor for retarding deterioration and maintaining cut flower life. Proper temperature control during storage will maintain the inherent high quality of flowers. The respiration rate is an index of the rate a flower uses stored sugar reserves or other respiration substrates and, therefore, is an indicator of storage life. The marked effect of temperature on respiration of carnations is shown in table 16. Respiration at 0°C is often only about one-tenth as high as that at 21°; hence, the stored food supply lasts longer at the lower temperatures. Figure 8 illustrates the pronounced value of refrigeration in reducing the respiration rate of narcissus. In roses also, temperature has a profound effect on respiration rates. The respiration rate is over three times as high at 15° as it is at 5° and over six times as high at 25° as it is at 5°. Another way of expressing this temperature effect is to say that 1 day's holding at 15° is equivalent to 3 days' at 5° (*839*). (Also see *483*.) Research on cut roses has shown that sugars in preservative solutions are important in extending the longevity by maintaining mitochondrial structure and function, not just in providing respiration substrates (*451*).

For maximum storage a temperature of −0.5° to 0°C is recommended for some flowers stored by dry-pack methods. Also, this low temperature greatly reduces ethylene production, which in turn can result in high-quality products that last longer (*246, 909*). Orchids, poinsettias, and anthuriums are among flowers that need to be stored at higher temperatures. At −0.5° to 0° mold invasion is almost completely inhibited and insects are inactive. Details of dry packing are given on page 84. The highest freezing point of many flowers is in the range of −2.2° to −0.6°. Where temperature controls allow fluctuations of ±0.5 degrees, a setting of 0° is safer than −0.5°.

Table 16
Respiration rate and heat evolution of carnations held 6 hours at various temperatures[1]

Temperature (°C)	Respiration rate (mg CO_2/kg•hr)	Heat evolution (Btu/ton•h)
0	9.7	89
10	30.0	275
20	239.0	2,191
30	516.0	4,730
40	1,053.0	9,653

[1] Data of Maxie et al. (*599*).

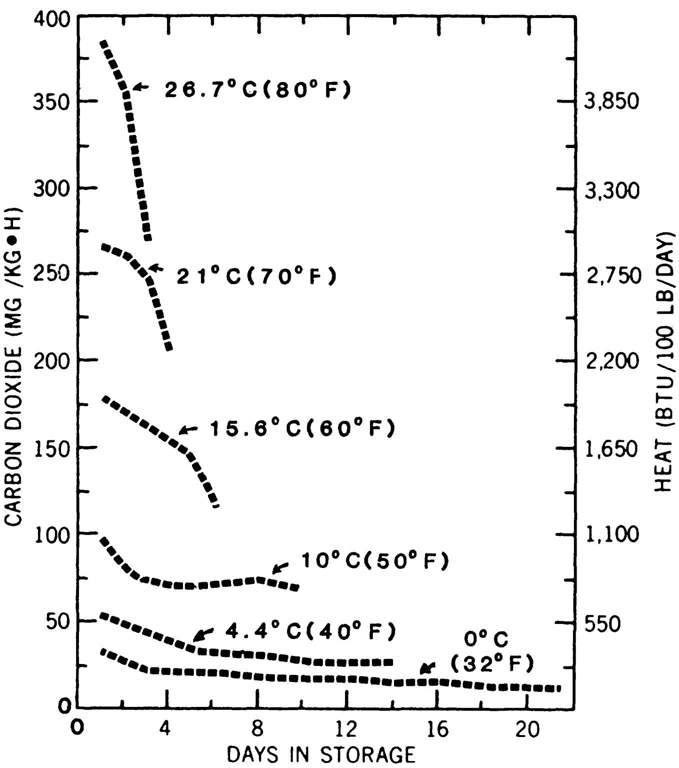

Figure 8
Respiration of cut narcissus stored dry at six temperatures. Data from Lutz and Hardenburg (*554*).

The highest recorded freezing point in some blooms is −0.5° for Easter lilies, −0.6° for gardenias, −0.5° for roses, and −0.7° for carnations (*1030*).

The temperatures and approximate storage periods given in table 15 are those recommended to ensure reasonable longevity of flowers after they are removed from storage. Storage at 4°C is probably more common at the wholesale and retail levels than at the grower level. Cut flowers for which 7° to 13° is recommended as a rule do not keep well when stored at a much lower temperature or may not develop satisfactorily after removal from storage. Flowers for which a storage temperature of −0.5° to 0.5° is recommended naturally develop and deteriorate more rapidly if stored at higher temperatures, such as 7° or above. Sometimes the changes occurring during storage are not immediately apparent; but the longer blooms are stored at −0.5° to 0.5°, the shorter their life when they are removed from storage. On the other hand, if short-lived or chilling-sensitive blooms that keep best at 4° are stored at −0.5° to 0.5°, the effect of this adverse condition may appear after they are placed at room temperature. It is possible that some of the flowers for which a storage temperature of 4° is recommended would keep longer if stored dry at −0.5° to 0.5°. However, further research is needed to establish optimum conditions.

Opening of storage doors should be kept to a minimum, as this causes temperature fluctuations that can be harmful to flowers. Some florists have installed their 0.5° to 0°C storage so that the entrance door opens to a cold room held at 4°. By this arrangement less cold air is lost by door opening.

For accurate temperature measurements, thermometers or thermocouples should be placed at the levels the flowers are being stored, and not just at levels convenient for making readings. Temperature may vary several degrees from floor to eye level (*909*).

For further information on temperature requirements, see *30, 64, 141, 369, 593, 599, 670, 703, 770, 830.*

Precooling Flowers

For cooling, most cut flowers are still simply placed, packed or unpacked, in a cold room. Only in recent years has forced-air cooling been used for flowers. Researchers in California pioneered the construction of forced-air cooling units for this application. Forced-air cooling allows packed boxes of blooms to be quickly cooled before shipping. Most flowers are now shipped by refrigerated trucks. As costly as air shipment is, flower temperatures are mostly too high (10° to 20°C range) (*369*). Forced-air cooling before shipping removes enough heat from the flowers to enable the refrigeration system on trucks to maintain proper flower temperatures in transit (*761*). It is also a convenient method of quickly removing field heat from blooms that are to be stored. Efficient operation of a forced-air cooler requires that the boxes be vented on each end. The flowers must also be packed so that no paper restricts air flow.

Forced-air cooling reduces flower temperatures by pulling 0°C refrigerated air through the packed boxes (fig. 9). In a typical system, vented boxes are placed in a refrigerated room and stacked next to an exhaust fan. The centrifugal fan pulls refrigerated air through the blooms, which cool by releasing their heat to the cool air (*238, 761*). The refrigeration system must be designed to maintain a temperature of 0° and a relative humidity of 95 to 98 percent, and to have a sufficient air-flow capacity. Precooling units are available that can cool from 4 to more than 100 boxes of flowers in less than 1 hour (*761*). Commercial testing of forced-air-precooled carnations, roses, and chrysanthemums showed beneficial effects on flower quality following transcontinental shipment (*237*). After precooling, blooms must be kept under continuous refrigeration during distribution for maximum benefit. Precooling has little or no value if low temperatures are not maintained during subsequent periods (*239*).

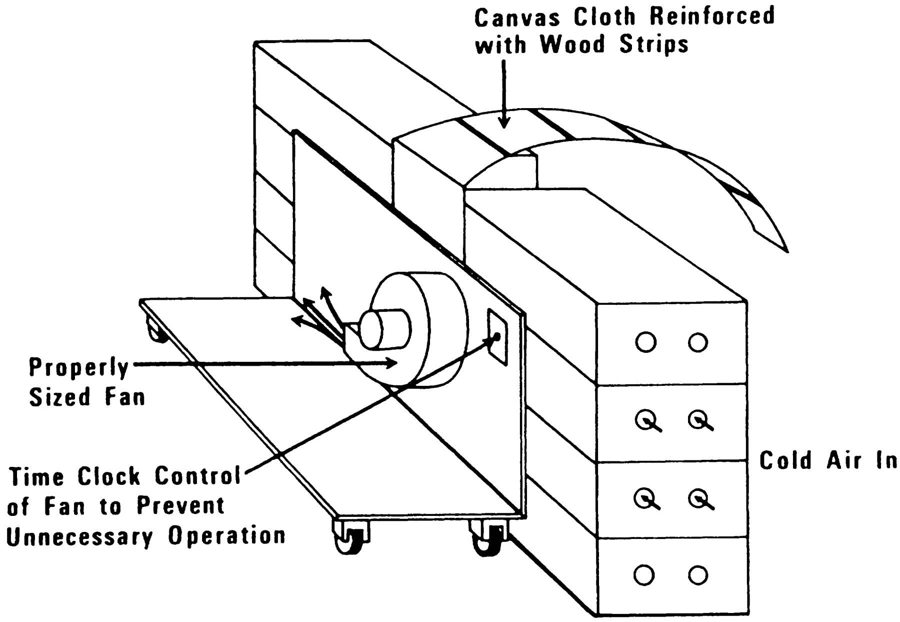

Figure 9
Portable forced-air cooler designed for 8 to 10 boxes of flowers. From Rij, Thompson, and Farnham (*761*).

Relative Humidity

A high relative humidity of 90 to 95 percent is recommended in refrigerated storage rooms held at 4°C or below to minimize moisture loss. Small deviations of 5 to 10 percent in relative humidity can reduce flower quality. The petals of some types of flowers become undesirably dry at 70 to 80 percent relative humidity. Carnations kept two to three times as long in a nearly saturated atmosphere as in an atmosphere at below 80 percent relative humidity (*397*). Also, with some species (for example gladiolus), floret development is faster at a high relative humidity than at a lower humidity at the same temperature. High humidity is essential to ensure good opening of bud-cut carnations and chrysanthemums.

Moisture loss in stored flowers is directly related to vapor pressure deficits (that is, to both relative humidity and temperature). Therefore, temperature variations in storage should be kept to a minimum. To do this, and also to save energy (*46*), requires that refrigerator doors be kept closed as much as possible.

For dry-pack storage, maintaining a high relative humidity in the moistureproof packaging or containers is fairly easy, since the atmosphere surrounding the flowers quickly becomes saturated.

Air Circulation

Forced but gentle air circulation should be provided with a blower or fans in flower storage rooms, but the blossoms should not be in a direct draft. Plastic or canvas baffles may be necessary. In modern storage rooms, circulating fans are positioned to pull rather than push the air through the room. Circulation at 15 to 23 m/minute (50 to 75 linear ft/minute) is adequate unless a large amount of heat must be removed quickly. Flower containers should be set on racks and spaced so that air can pass between and behind them. Wooden, slatted false-floor racks, raised at least 5 cm (2 in) from the floor, also are desirable to allow circulation of cold air under the flower containers. All containers should be stacked so that at least one surface is exposed to freely circulating air. Without good forced-air circulation, air layering and hot spots may be troublesome or cold spots may cause freezing.

Dry-Pack Storage

For maximum storage, many flower species keep best if packed without water in boxes or drums that prevent moisture loss and are stored at −0.5° to 0.5°C. This temperature will allow longer storage than at 2° to 3°. Wet storage in water or preservatives is the common practice for short storage periods (that is, a few days) (*891, 909*). Some flowers like freesias, dahlias, and gypsophila store better and longer in water or preservative than under dry-pack conditions (*314*).

For dry storage, flowers are normally harvested early in the morning when fully turgid, handled dry, and promptly packed in moisture-tight containers before any wilting occurs. Only the best quality flowers should be held in long-term refrigerated storage, since even under the best conditions some deterioration occurs. Poor flowers do not become better in −0.5°C storage; they become worthless in a short time (*770*). Diseased flowers may ruin others in the package. Pioneering research on dry-pack storage was done by Neff (*657*), Post and Fischer (*246, 730*), Mastalerz (*589, 590*), Hawes and Link (*381*), and Whiteman and coworkers (*1032*) and was reviewed by Sheehan (*830*). For example, in 1939, Neff reported that carnations in dry pack at −0.5° kept for as long as 39 days, with almost as long a useful vase life afterwards as freshly cut flowers (*657*). More commonly, the period for commercially holding dry-packed flowers in advance of holidays is only 1 to 3 weeks.

Many species of cut flowers can be packed directly after they have been cut and promptly cooled in forced air, without any hardening or conditioning in water. To avoid such conditioning is particularly important for the successful dry storage of roses. Conditioning red roses in water before dry storage increases the extent of blueing of the petals that develops during extended storage (*590*). Chemical analyses of carbohydrates in stored flowers have shown that the depletion of these food reserves is more rapid from flowers stored in water than from dry-packed flowers.

Some flowers like gladioli, carnation buds, and *Strelitzia* store longest if they are pulsed or preconditioned with a preservative solution before they are placed in dry-pack storage (*314, 475, 782*). Gladioli can be stored at 2° to 5°C but only for 5 to 8 days.

Several kinds of containers can be used for dry-packing, but they must be moisture retentive. Fiber drums are satisfactory if they have a wax or film interior coating. Often, separate film liners or polyethylene bags are used in drums or regular flower-shipping boxes. After the container is filled and the flowers are cooled to a low temperature, the liner is carefully folded over the flowers or the bag is tied. It is critical to cool flowers adequately before the bag is sealed and the cover inserted. No special effort should be made to seal the film or container gastight, although some flowers might benefit from the modified atmosphere. Others might be injured if oxygen drops too low or carbon dioxide accumulates excessively. Also, with perforated or nonsealed films there is less condensation and thus less chance of botrytis infection occurring (*100*). Usually, moisture-absorbent paper, such as newspaper, should not be included (*770*). However, tissue paper may be needed in polyethylene-lined boxes, where contact with condensed moisture may be harmful to blooms such as carnations and daffodils. Botrytis decay can be a big problem in storage. Containers should be filled with flowers to reduce free air space and minimize moisture loss (*246, 730*). Packing should not be so tight that bruising and discoloration occur. When flowers are packed in several layers, it is desirable to support the heads of each layer with cleats to prevent crushing the blooms below. Cleats are unnecessary if flowers are stored upright in drums or containers, as the weight rests on the stems

Some flowers, notably snapdragons and gladioli, are sensitive to gravity and must be stored and shipped upright to prevent the spikes from exhibiting geotropic bending (*940, 1031*) and thus becoming unsalable. Low-temperature storage reduces but does not prevent bending of horizontally stored gladioli.

The goal of all dry-pack storage is to increase the marketing period and prevent deterioration so that on removal from storage the flowers will last as long as freshly cut ones. Flowers stored too long will have a short vase life. Table 15 or the notes on individual flowers may be consulted as to which ones may be stored at −0.5° to 0.5°C.

Storage in Water or in Preservative Solutions

One of the most important factors determining cut flower life is the ability of the flower to maintain turgidity—that is, good water relations. One of the functions of flower preservatives is to maintain a turgid flower. Cut flowers that are normally marketed or held for short periods (not extended dry storage) should immediately be placed in containers of warm water (38° to 43°C) or, better still, warm preservative solution and held in refrigerated rooms at recommended temperatures (often 3° to 4°). This freshening and hardening period for at least 4 to 6 hours and often overnight or longer overcomes wilting and hydrates the tissues before shipment (*500*). Spilling water on the blossoms should be avoided, since this might result in spotting or discoloration. Stem sections below water should be stripped of foliage. Since only the ends of the stems take up water, a deep container of water is no more beneficial than one with only enough water to allow 10 to 15 cm (4 to 6 in) of the stems to be immersed.

Warm water at 38°C is recommended for most freshly cut flowers, as it is taken up more rapidly and in greater quantity than colder water. Warm-water uptake and retention are also better in 4° storage than in warmer storage (*891*).

Water quality has an important effect on the keeping quality of cut flowers and decorative foliage. Ideally, the water should contain little salts; deionized water or distilled water is often better than tap water with or without preservatives (*756, 908*). For example, roses held in tap water lasted 4.2 days as compared with 9.8 days in distilled water. However, the quality of tap water in most metropolitan areas is now good and is satisfactory for cut flowers. High salts in water supplies can be removed by commercial deionization or reverse osmosis equipment (*909*). Fluoride levels of 1.0 p/m or greater can reduce the lasting quality of some floral crops, especially gladioli and gerbera (*583*). Levels of 1.0 p/m fluoride approximate those found in municipal fluoridated water.

Using floral preservative solutions throughout marketing channels is most important. Preservative use reduces flower waste, improves flower longevity and general qualities, and improves consumer satisfaction. Early work on the value of preservatives is described in references *1, 397, 583, 593, 658*, and the immense literature in this area is reviewed in references *314, 772.* Flower longevity is often doubled or tripled by the use of preservatives. For example, carnations placed in preservative solutions immediately after harvest kept 16.9 days at room temperature but only 6.8 days in tap water (*593*). Several commercial preservative materials are available. They usually contain a source of energy, such as sugar (sucrose or table sugar), a biocide to inhibit the growth of micro-organisms (silver nitrate, 8-hydroxyquinoline citrate, or a quaternary ammonium compound), and an acidifying agent (often citric acid) to reduce the pH to 3 to 3.5 (*756*). Lower pH level improves water uptake. Sucrose serves as a substrate for respiration and other metabolic activities and acts as an osmoticum. Both sucrose and 8-hydroxyquinoline citrate tend to close stomates, thereby reducing transpiration (*314, 495, 678*). The biocides hold down bacteria growth and help prevent bacterial plugging of water-conducting tissues (*495, 575*).

Three types of preservative treatments are used commercially (*756*):

1. **Vase solutions.** Cut flowers are often held continuously in vase solutions containing both sucrose at a low concentration and a biocide to lengthen life.

2. **Bud-opening solutions.** Bud-cut flowers such as carnations (*240, 345, 401, 473, 478*), chrysanthemums (*477*), gladioli (*574*), snapdragons (*495*), and asters (*1013*) are held after harvest or after extended storage in a solution containing sucrose (usually at a higher concentration than for vase solutions) and a biocide for several days, until the flowers open. Bud-cut flowers could not be successfully stored or shipped and opened if it were not for such solutions.
3. **Pulsing solutions.** Buds or open flowers are treated for 16 to 20 hours in a vase solution containing sucrose at a relatively high concentration (5 to 20 percent) and a biocide before shipping or marketing. The special value of pulsing treatments is that they are effective in extending vase life even when preservatives are not used subsequently at the wholesale or consumer level. Gladioli stems pulsed with a 20-percent sucrose solution containing silver nitrate for 20 hours at 21°C before storage (7 to 10 days) resulted in greater floret opening and size than those not pulsed (*475*).

More recently the value of pulsing with a silver thiosulfate complex has been demonstrated. Silver moves readily in cut flower stems if it is present as the thiosulfate complex, prepared by combining solutions of silver nitrate and sodium thiosulfate (*987*). Silver ions from silver nitrate are not readily translocated in cut flower stems. Silver ions do inhibit the action of ethylene and delay senescence (*6*). Immersion of carnation stems in a silver thiosulfate solution for a 10-minute pulse at 24°C doubled their longevity from 5 days to more than 10 days (*757*).

Nonmetallic (plastic) containers should be used for holding preservative solutions. If metal containers are used, there is a chance that some preservative constituents could be inactivated by the metal ions (*909*).

Conditioning or Hardening

Cut flowers and many florist greens should be conditioned on removal from −0.5° to 0.5°C dry storage before shipment to market or they may arrive in poor condition. Conditioning is necessary to hydrate the stems and overcome slight wilting from loss of moisture before or during dry storage. Conditioning, or hardening, consists of recutting the stems (remove about 2 cm) and placing the product in vases with warm 38° to 43° (100° to 110°F) water in a 4° storage room for 6 to 12 hours (*588, 730*). Cold water should be avoided, and good quality water or deionized water should be used. Deionized water is better than tap water only if the tap water is of poor quality (that is, high in soluble salts). The conditioning period allows the stems to absorb water, so the leaves and flowers regain turgidity. Conditioning in warm preservative solution instead of water will markedly improve the subsequent keeping quality of many flowers. After conditioning, stored flowers can be bunched, packed, and shipped in the same manner as freshly cut flowers.

Conditioning freshly harvested flowers improves the opening of certain species (iris, gladioli, roses) and allows longer vase life (chrysanthemums, carnations). Here again conditioning for 3 to 24 hours before shipment by using a proper preservative solution containing sugar, a bactericide, and a weak acid is usually much more effective than conditioning in water (*313*). Longevity of carnations may be doubled by a 24-hour conditioning in a preservative solution containing 5 percent sugar.

After transport to market and before arranging, many cut flowers and florist greens should be conditioned. This conditioning consists of recutting the stems and placing the item in a 27° to 38°C (80° to 100°F) preservative solution in a 4° cold room with 90 to 92 percent relative humidity for 2 to several hours (*891*). Light intensity in the holding area should be a minimum of 1,100 lux (100 fc).

Sanitation

Old, dead, and decaying plants and plant parts should be kept out of refrigerators and work areas. They are a source of ethylene gas as well as of decay-causing micro-organisms (*1037*).

Water cans, buckets, vases, storage racks, and rooms need regular cleaning with a good detergent or soap containing a disinfectant to keep micro-organisms under control. A chlorine rinse or soak of containers is very effective. Cleaning at least once a week is desirable for flower buckets, and it should be followed by a plentiful hot water rinse. Washing will eliminate the presence of bacteria, fungi, or yeasts which can shorten the life or cause the decay of flowers and decorative foliage. Various types of micro-organisms, especially bacteria, have been implicated as being a primary cause of stem blockage in harvested fresh flowers. With stem blockage, water uptake is limited and wilting and senescence are hastened. In one study, the bacteria most frequently isolated from cut flower containers were *Achromobacter, Bacillus, Micrococcus,* and *Pseudomonas* species (*252*). Most of the types associated with ornamental crops are soilborne and waterborne bacteria.

Stems and leaves of flowers and greens are usually contaminated with bacteria, so they quickly contaminate clean vase water. This is a reason why most preservative solutions contain antimicrobial chemicals. Chlorine in one form or another is widely used, as are other common bactericides (*494, 579, 770*). Keeping flowers in a cold room will retard the growth of micro-organisms in containers. It is important to remove all leaves that are submerged in water in the container so that the food supply for bacteria is reduced.

Ethylene and Other Volatiles

Production of floriculture crops in or near urban areas is hampered greatly by air pollution. The major culprit is ethylene gas, but other volatiles in exhaust gases (carbon monoxide, propylene, acetylene, and

other low-molecular-weight hydrocarbons), industrial smoke, and natural gas also are harmful to plants. The presence of even minute quantities of ethylene gas in greenhouses, in storage, or anywhere in the chain of distribution greatly affects the keeping quality of flowers, greens, and woody ornamentals. Ethylene at levels as low as 30 to 60 parts per billion causes damage to carnations (*971*), and at 2 to 5 p/m it may injure foliage plants. Excellent reviews of the physiology of ethylene formation and preharvest and postharvest effects of ethylene on crops have been published (*128, 370, 383, 772*). It is imperative that steps be taken to reduce or eliminate ethylene in areas where flower and ornamentals are handled.

Common symptoms of ethylene injury (toxicity) include epinasty, or downward bending of leaves; premature withering or rapid aging; dropping of leaves, florets, or berries; yellowing of foliage; and inward curving and closing of opened petals (sleepiness in carnations). Snapdragons, stocks, larkspur, roses, and calceolarias are among the flowers that drop petals or florets on exposure to ethylene. Cattleya orchids may be injured by exposure to 0.1 p/m ethylene for 8 hours, the injury evidenced as drying and bleaching of the sepals (*187*).

Where does the ethylene come from? There are several possible sources. Many flowers give off ethylene, especially during senescence, and enough may accumulate to cause those flowers to injure themselves or other ethylene-sensitive blooms in the same greenhouse or storage (*669*). Arborvitae produces large amounts of ethylene. Ethylene is also produced by diseased plant tissues. Chrysanthemums infected with *Botrytis* produce large amounts of ethylene. Many fruits and vegetables give off copious quantities of ethylene and, hence, should never be stored in the same cold room with flowers. Apples and pears are particularly damaging to flowers, even in 3°C storage. It is better not to store ripening fruits in the same building with flowers. Other sources of ethylene and other damaging volatiles are leaks from gas mains; exhaust fumes from internal combustion engines, including transport vehicles; improperly vented greenhouse space heaters; manufacturing plants; and chopped or mechanically damaged leaves.

Some of these sources of ethylene are beyond the control of growers or warehouse operators. However, there are some precautionary measures. Flowers and greens known to be heavy producers of ethylene should not be stored with the more sensitive flowers or plants but in a separate room. Diseased flowers or foliage should be removed promptly because of their high ethylene production. Probably most important, temperatures should be controlled. Storage should be at 4°C or below, where possible, because both ethylene production by flowers and physiological activity of ethylene are reduced at low temperatures. The sensitivity of carnations to ethylene increases dramatically with increasing temperature (*599*). Carnations are about 1,000 times as sensitive to ethylene when held at room temperature as they are when held at their proper storage temperature (−0.5°). Flowers from ethylene-free storage will keep longer for consumers, and air filters to remove traces of ethylene can be installed in storage rooms. The active absorbent in such filters is often potassium permanganate or brominated charcoal and must be replaced or recharged periodically. Filters probably will not be effective if ethylene levels are high.

Good ventilation in storage to remove volatiles can be most helpful; it should ensure a complete air exchange in floral coolers every hour. Also, research has shown that carbon dioxide gas (5 percent) during storage is sufficient to prevent sleepiness in carnations in the presence of ethylene (*864, 971*). Ethylene inhibitors, such as silver thiosulfate, can prevent premature or undesirable abscission and sleepiness (*987*). Treatment with silver thiosulfate can prevent ethylene-induced abscission of petals or florets of Christmas cactus, snapdragon, geranium, hydrangea, begonia, and lilies. Other chemicals are available that can inhibit ethylene synthesis in flowers, but these are not used commercially (*1000*).

Controlled-Atmosphere and Hypobaric Storages

The principles of controlled-atmosphere storage (CA) are discussed in an earlier section (p.23). As a result of considerable research on floral crops, the general conclusion is that CA storage is not recommended for cut flowers. The margin of safety is small before phytotoxicity occurs, costs are high, and there is not enough volume of any one cultivar to warrant its use. Some flowers benefit from increased concentrations of carbon dioxide in the storage atmosphere or in packages under carefully controlled conditions (*984, 990*). However, high levels of carbon dioxide may also be injurious. Carbon dioxide at a certain concentration may be beneficial at one temperature and injurious at lower temperatures. Generally, flowers refrigerated in an atmosphere of 0.5 to 3 percent oxygen will respire and deteriorate more slowly than flowers refrigerated in normal air, which contains about 21 percent oxygen. Good summaries of results with different CA conditions for different flowers have been published (*760, 906*).

Early work with roses, in 1930, showed that carbon dioxide levels of 5 to 15 percent in storage retarded bud opening and prolonged their life (*948*). The quality of carnation blooms stored 4 to 5 weeks at 0°C in 1 to 3 percent oxygen has been reported both as improved (*732, 948*) and as of little or no economic benefit (*326*). It would appear that a more practical method of obtaining long-term storage of carnations is to use dry-storage methods—wrapping mature tight buds in newspapers, then sealing them in polyethylene bags, and holding the bags at −0.5° to 0°. The sealed bag provides beneficial high humidity conditions during storage. A preconditioning treatment before storage in a preservative solution containing silver thiosulfate, 8-hydroxyquinoline citrate, and sucrose has been successful (*782*).

After storage the buds may be opened in a preservative solution, with 14 to 16 hours of light per day at an intensity of 2,200 to 3,200 lux (200 to 300 fc) before marketing.

King Alfred daffodils, normally stored dry at 0°C, may also be stored successfully 3 weeks at 0° or 4° in an atmosphere of 100 percent nitrogen and have a display life as good as or better than that of freshly cut flowers (*692*). Longer storage reduces subsequent display life.

Encouraging results with modified atmospheres have been obtained with consumer-packaged flowers and with sealed film-lined boxes of flowers. Here it may be that the flowers develop, through their respiration, a beneficial atmosphere of reduced oxygen and increased carbon dioxide. The species and quantity of flowers stored determine to a large extent the alteration of the carbon dioxide and oxygen levels in the package. An alternative is to select a package made of moisture-proof cellophane, polyethylene, or other film with just enough permeability to oxygen and carbon dioxide as to allow the bag to maintain an atmosphere which will support respiration at a reduced rate. Then, after such a package is filled with flowers, it is flushed with an atmosphere known to be beneficial for that flower before sealing. (See *381*.) However, close control of the atmosphere is almost impossible, and results occasionally may be erratic.

The principles and experimental application of **hypobaric** (low pressure) storage for floral crops have been reviewed (*129, 212, 760, 906, 907*). In this process, perishable commodities are maintained under refrigeration while being continuously ventilated with water-saturated air at a controlled subatmospheric pressure. Laboratory tests indicate that some cut flowers store best at pressures between 10 to 60 mm Hg at 0° to 2°C (*129, 907*). Hypobaric ventilation (40 to 60 mm) with moist air at 0° markedly extended the longevity of carnations, chrysanthemums, roses, snapdragons, gladioli (at 2°), vanda orchids (at 12°), chrysanthemum plants, Easter lily plants, cuttings of carnations and chrysanthemums (at 0° to 1°), and poinsettias (at 10°). Longevity was often doubled by hypobaric storage over normal refrigerated storage (*129, 907*). Particularly noteworthy were results showing that bud-cut carnations can be kept 9 weeks in hypobaric storage with no loss in ability to open or in longevity. However, we now know that use of an antiethylene compound, such as silver thiosulfate, is just as important if not more important than low-pressure storage with carnations (*907*). The extremely low ethylene levels in flowers during hypobaric storage plus low oxygen partial pressures and refrigeration are mainly responsible for prolonging the life of floral crops. Both roses and chrysanthemums respond favorably to low-pressure systems. A key to the success of low-pressure systems is the careful control of temperature, relative humidity, air exchange, and pressure—not just the low pressure aspect (*760, 907*). While some laboratory and commercial tests of hypobaric storage are promising, other tests have shown little benefit. To what extent hypobaric storage will become a reality for the floriculture industry is still unknown. Initial investments for a hypobaric system are high.

Light

Exposure of flowers or flowering plants to high light conditions prior to harvesting enhances their accumulation of carbohydrates and may thereby provide them with longer lasting qualitites. Also, light acclimatization of foliage plants prior to harvest improves their longevity. During storage and transport most tropical foliage plant species will tolerate darkness for 5 to 10 days without losing quality. Storage of some floral crops in light will extend postharvest life (*909*). Storage in the dark for relatively brief periods (1 to 3 days) generally does not reduce postharvest quality. It is recommended that some light be provided in storages whenever possible. When no light is provided for extended periods, leaves may yellow and flowers may fall off or die. Research in Florida has shown that cut flowers still have the capacity to produce carbohydrates through photosynthesis if light is provided in cold storage (*1051*). Cut chrysanthemums keep longer with light (500 to 1,100 lux) than without light. Poinsettia and chrysanthemum plants should be removed from shipping boxes promptly, as they do not tolerate darkness for more than a few days. African violet and azalea plants stored in complete darkness for several days will drop flowers and leaves, respectively. To open bud-cut carnations and chrysanthemums, it is essential to provide 1,100 to 2,200 lux of light continuously and to use bud-opening solutions (*474, 577*). The display area for floral crops at wholesale and retail levels should provide 1,100 to 2,200 lux of light for 16 hours a day to maintain foliage and encourage continuous development of flowers.

Storage and Handling Details for Certain Flowers

Anthurium flowers are long lasting and often remain in excellent condition in water for 3 to 4 weeks at 13°C (*891*). They should be harvested when the spadix is three-fourths mature, because at this stage the flower's appearance is best (*452*). Storage temperatures of 7° and below will cause darkening, a symptom of chilling injury. The use of preservatives in the water is very beneficial for some cultivars, extending the vase life of anthuriums four times over that of flowers in water (*16, 452*). In the absence of refrigeration facilities, controlled atmospheres are beneficial at ambient temperatures (*19*).

Asters and **heath** can be held at 4°C for 1 to 3 weeks, but normally only 1 week. Vase life of China-asters can be markedly extended by pretreatment of the stems in silver nitrate or Physan-20 (*141, 472*).

Bouvardia can be held at 0° to 2°C for 1 week or at 4° for 4 days.

Calla blooms should be harvested just before the spathe shows signs of curling downward, and harvesting consists of cutting or pulling from the rhizome. Freshly harvested blooms of common and golden callas can be stored for 7 days at 4°C. Callas that have been subjected to

hard forcing should be held for about 24 hours at 10° previous to storage at 4°. Callas intended for storage should be tied near the ends of the stems and also tied loosely below the blooms.

Camellias are not customarily stored. However, they can be kept in storage in good condition for 3 to 6 days at 7°C.

Carnations are best stored dry at −0.5° to 0°C with 90 to 95 percent relative humidity, and the use of polyethylene-lined containers is recommended to help maintain the high humidity. Carnations were one of the first flowers to be successfully stored by dry-pack methods (*246, 657, 730*). Dry-pack storage is better than storage in water, and storage near 0° is better than at 4° (*657*). The container should not be completely gastight; otherwise, damage from anaerobic respiration may result. Also, tissue or other paper should separate the blooms from the moist polyethylene to avoid damage. After dry storage, carnation stems should be recut and then conditioned in warm preservative solution in a 4° cooler with high relative humidity for several hours before use or shipment.

Carnations may be cut just after the petals have unfurled. They can be dry stored 3 to 4 weeks; in commercial practice 2 weeks is more common. In recent years, much larger quantities of both U.S.-grown and imported carnations are cut at the large-bud stage (2- to 2½-cm, or ¾- to 1-in diameter). Bud-cut carnations can be dry stored longer than open blooms, reportedly for 4 to 12 weeks at −0.5° to 0°C. Both bud-cut and open flowers should be precooled immediately after harvest. Flowers from dry-stored buds have lasted as long as buds opened immediately or as long as flowers opened on the plant (*345, 401, 473*). Some of the advantages of bud harvesting are that buds suffer less damage in handling, require less shipping and storage space, have longer storage potential, and can be inventoried and opened as needed. Buds do not open to full maturity or size in water. They are opened in a preservative solution or special "opening solution" at 20° to 24° with 50 to 70 percent relative humidity and flourescent light of approximately 1,100 to 1,600 lux (*892*). Either good quality or deionized water is satisfactory for preparing the preservative solution (*909*). Usually, the purer the water, the longer the carnations last.

Preservatives are extremely useful for carnations, doubling or tripling their vase life. They should be used at all stages in the chain of distribution. Some preservatives contain silver, which protects the flower against the effects of ethylene. Carnations are one of the most sensitive flowers to ethylene. However, they are much less sensitive to ethylene at recommended storage temperatures of −0.5° to 0°C. Pulse treatments before storage or marketing with ethylene-inhibiting chemicals such as silver thiosulfate can greatly extend subsequent vase life (*286, 757, 935, 986, 999*). The stems of carnations should always be recut before they are placed in water or preservative solution.

Chrysanthemums store very well and also have a long vase life. Both standard (large flowered) and pompom types are generally harvested commercially when the flowers are almost completely open. Subsequent vase life is enhanced when they are stored under lights (800 to 1,100 lux) at −0.5° to 0°C by dry-pack methods. A storage period of 3 to 4 weeks is practical. Storage at 2° to 5° is less desirable than 0° since botrytis infestation is greater at warmer temperatures (*246*).

Chrysanthemums can also be harvested in the bud stage if special attention is paid to bud size and bud-opening procedures after storage (*477, 577*). Medium to large buds (6 to 8 cm) of standard chrysanthemums are best, and a storage period of 2 to 3 weeks is possible at −0.5° to 0°C. Longer storage of buds can result in poor flower opening and flowers with a flat appearance. Use of an opening solution containing a biocide and sucrose is essential for successful bud opening (*477, 577, 909*). Medium-size buds take 5 to 7 days to open. Stored buds open as well as freshly harvested buds in opening solutions, but flowers from buds have a vase life slightly less than freshly harvested fully open flowers. Pulsing or loading stems with a preservative solution for 16 hours before shipping at 2° is beneficial in extending longevity after shipment (*476*). Preservatives containing 5 percent sucrose and the biocide Physan are effective for pulsing.

Columbine, delphinium (hardy and annual larkspur), **baby primrose, forget-me-not,** and **butterflybush,** or **buddleia,** shed their petals quickly at any storage temperature. These flowers cannot be stored at temperatures much lower than 4°C for longer than 1 or 2 days without serious impairment to flower longevity. For marketing, bunches of these flowers may be wrapped to prevent tangling with adjacent bunches.

Daffodils will keep 1 to 3 weeks at 0° to 0.5°C with dry packaging (*730*). Field-grown King Alfred daffodils cut when the flowers are at the "gooseneck" stage will store for 10 to 14 days at 0°. Conditioning before dry storage is not needed. Greenhouse daffodils grown under good conditions will store dry 3 weeks at 0° and still last as long as freshly cut blooms. One to two weeks' dry storage is more common. They should be stored in a vertical position. The daffodil has been successfully stored in the absence of oxygen, but this practice is not used commercially. Flowers stored for 3 weeks at 0° or 4° in 100 percent nitrogen lasted as long as freshly harvested daffodils (*692*). If narcissus are held in water or preservative at 4° immediately after harvest, other flowers should not be placed in the same container. (See also *589, 673, 909*.)

Dahlias can be held satisfactorily for 3 to 5 days at 4°C. The base of the stems should be immersed in boiling water for 5 to 10 seconds before storage so that the stems will not ooze substances that block water uptake. Each time the stems are recut this treatment should be repeated.

Common **foxglove** and garden **phlox** are not usually satisfactory for storage, but they can be held for 1 to 2 days at 4°C.

Gardenias, although rarely stored for long periods, may be kept satisfactorily for 2 weeks at 0° to 1°C. A temperature of −0.5° may occasionally cause freezing injury. Gardenias are usually not placed in water after picking and are often "collared" to prevent bruising. (See *246, 730, 891*.)

Gladiolus should be cut when one or two of the lowest florets show color but are still at a relatively tight bud stage. Gladiolus can be stored a maximum of 5 to 8 days at 2° to 5°C. A few cultivars may be chilled at 2°, and floret opening may be unsatisfactory after 8 days' storage (*284, 1014*). The spikes should always be shipped and stored in a vertical position to prevent geotropic bending (*940, 1014, 1031*) and are usually tied in bunches of 10. Flowers wrapped with moistureproof materials before storage or shipping keep better than those wrapped with kraft paper (*576, 1014*), but industry still prefers paper. Pulsing gladiolus stems at 21° with 20 percent sucrose in combination with silver nitrate before storage improves later floret opening (*475*). Flowers kept continuously in preservatives have greater longevity than those kept in water (*576*).

Gypsophila (babysbreath) does not store well in dry storage. It can be stored in water or a preservative solution at 4°C for up to 3 weeks. For a long vase life at room temperature a preservative is necessary (*141, 582, 891*).

Hyacinths, freesias, and **squills** can usually be held satisfactorily for 2 weeks at 0° to 0.5°C or 1 week at 2°. If stored dry in boxes, flowers should be kept vertical, with the blooms up to prevent bending (*141*).

The various bulbous or **Dutch irises** stored in the bud stage can be held 1 to 2 weeks and sometimes longer at −0.5° to 0°C (*439*) by the dry-packed method. Flower maturity is very important, as buds cut too tight will not open. Dutch iris will keep only about 1 week at 1° in water. If conditioned properly on removal from dry storage, blooms should have a vase life of 5 days at room temperature. (See *288, 730, 891*.)

Easter (*Lilium longiflorum*), *speciosum rubrum*, regal, and **goldband lilies** should be cut for storage when the tips of petals (perianth) begin to reflex. Blooms forced at relatively high temperatures should be kept at a temperature of about 10°C for about 24 hours before being stored. These species can be held in storage at 0° to 2° for 2 to 3 weeks. (See *246, 891*.)

For **lilies-of-the-valley,** the proper cutting stage is just after the terminal bell (floret) has lost its deep-green color. At this stage it should appear yellow-green, with the lower three of four bells (florets) open. Cut lilies-of-the-valley can be stored satisfactorily 2 to 3 weeks at −0.5° to 0°C with dry packaging (*246, 730*). In water, they will keep 1 week at 2°. These flowers are usually tied with foliage in bunches of 25; and it is best to wrap the bunches loosely in heavy waxed paper, with the tops and bottoms left open.

Lupine, clarkia, stevia, common stock, candytuft, cornflower, feverfew, blue laceflower, English daisy, calendula, or **pot marigold, sweet violet,** and common perennial **gaillardia** are not usually held at temperatures lower than 4°C and cannot be stored with good results for much more than 3 days. **French marigolds** can be stored 1 to 2 weeks at 4° (*659*). **Stock** flowers deteriorate rapidly if heating occurs. Bunches should be separated enough to allow rapid cooling. The longevity of stocks can be at least doubled by using preservative solutions (*496*).

Orchids keep longest if cut as soon as they reach a salable condition. A 2-week storage period at 7° to 10°C is maximum for many cultivars, and hardening in 27° water for a day at 4° before dry packaging is recommended (*829*). Storage below 4° causes chilling injury in some cultivars. Cattleya orchids stored 3 to 4 days at −0.5° will develop severe chilling injury (discoloration) on removal. A storage temperature of 7° to 10° seems best for *Cattleya*. *Cymbidium* and *Paphiopedilum* are more tolerant of low temperatures and can be stored 2 to 3 weeks at −0.5° to 4°. However, flowers of the last two genera have excellent longevity on the plant, often lasting 1 to 3 months. Hence, there is little advantage in cutting and storing these at lower temperatures than 7° to 10° (*730, 829, 891, 909*). Vanda orchids keep best at 13°. When one vanda flower (Miss Joaquin) in a pack starts to fade, others begin to fade (*514*). Ethylene gas given off by the fading bloom causes the damage. For short storage and for marketing, most kinds of orchids are usually shipped in glass tubes containing water and held at 7° to 10°. The water level should be checked periodically to ensure that there is sufficient water to maintain freshness (*891*).

Peonies showing color in the tight-bud stage can be stored dry at 0° to 1°C for about 2 to 6 weeks; in the loose-bud stage they can be held satisfactorily for 2 to 3 weeks (*680, 730*). There is no value in sprinkling the foliage or conditioning in water before storage (*404*).

Poinsettias should be cut when the colorful bracts are fully developed. The cut ends are usually dipped in boiling water for 10 seconds to prevent vascular blockage by latex. Sometimes the cut stems are held 40 to 50 seconds in 60 to 70 percent rubbing alcohol instead of boiling water. If it is necessary to hold cut poinsettias during the Christmas season for 4 to 7 days, a minimum temperature of 10°C is recommended. Any change of environment from greenhouse conditions increases the tendency of poinsettias to shed their foliage. However, with new cultivars, foliar abscission is not the problem it once was. Preservatives in the vase water are helpful.

Poppies and **mignonettes** should have the base of their stems immersed in boiling water for 10 seconds before storage. Placing stems in alcohol as with poinsettias is also effective. After either treatment, which keeps the stems from oozing substances that block water uptake, these flowers can be held 3 to 5 days at 4°C.

Ranunculus flowers keep substantially better at 0° to 5°C than at 10° or 15° (*656*). Extended storage beyond 7 to 10 days at 0° or

5° increases the rate at which the flowers senesce when removed from cold storage.

Roses should be harvested when at least two sepals of the calyx on the buds reflex. Harvesting of immature buds often results in bent necks and/or failure of the buds to open. Harvesting mature flowers reduces longevity. Roses should be precooled and hydrated immediately after harvest. For extended storage of up to 2 weeks, dry packing in moistureproof containers at −0.5° to 0°C is best for roses (*246, 658, 909*). Most authorities agree that roses should not be placed in water before low-temperature dry storage. Blueing of red roses is worse when flowers are hardened in water before storage (*590*). On removal from dry storage, roses should be recut and conditioned in warm (38°) preservative solution in a 4° room for a minimum of 4 to 6 hours before shipping. This conditioning period is essential for success.

For short storage of 4 to 5 days, roses are more commonly stored in deionized water or a preservative solution at 0.5° to 2°C immediately after cutting. Conditioning for at least 3 to 4 hours in preservative solution after cutting and before shipping is an absolute requirement (*909*). A high (90 to 95 percent) relative humidity is desirable. After conditioning, the roses may be graded. Mechanical or hand stripping of the lower one-third of the leaves is recommended and does not reduce flower longevity as long as the bark is not excessively damaged. Then, the roses can be placed back in the cooler in a preservative solution or packed for shipment. If the transport distance is short, shipping in preservative solutions is recommended. For air shipment, flowers are taken from the solutions, placed in black plastic bags within containers, and kept as cool as possible above freezing during transit (*482*).

Roses should be stored in the dark for long life and to minimize the problem of bent necks. Other procedures helpful in minimizing bent neck are (1) bring roses to the cooler as soon as possible and/or wrap them in polyethylene to maintain a high humidity, (2) use preservatives in storage and conditioning solutions as well as in pulsing solutions (the use of preservatives alone has greatly aided the rose industry in controlling bent neck), (3) recut stems under water each time roses are returned to water or preservative solution (*482, 1082*).

Upon receiving roses shipped dry or with ice, wholesalers and retailers should cut off about 2 cm (1 in) of stem and condition the flowers in warm (38° to 43°C) preservative solution in the cooler for at least 3 hours before use. Many retail shops do not keep their refrigerators cold enough, keeping them instead at 4° to 5°, which is warmer than recommended. Holding temperatures of 0.5° to 2° are best for roses (*482, 893, 909*). Floral preservatives should be used throughout marketing, because they can easily double rose life.

Snapdragon spikes can be held 3 to 4 weeks at −0.5° to 0°C by the dry-pack method (*589, 758*). They should be cut just after the lower five to six flowers have opened. Spikes will also store for 8 to 10 days at 5° in water, but they will have much better quality and last longer if held in preservative solutions (*441, 753, 1000*). Like gladioli, snapdragons need to be stored in an upright position because of rapid geotropic bending if left horizontal. Dropping or "shelling" of florets may increase if the spikes are exposed to ethylene. However, new cultivars hold their florets much better than old ones.

Statice and **strawflower** can be held in the fresh state at 2° to 4°C for 3 to 4 weeks (*30*). These flowers are often dried and retain their original color and shape for months.

Sweet peas can be held up to 2 weeks at −0.5° to 0°C by the dry-pack method (*730*).

Tulips keep very well in dry storage at −0.5° to 0°C. Successful storage of 4 to 8 weeks in moistureproof dry packs or in modified atmospheres has been reported (*125, 589, 667, 730, 909, 990, 1032*). However, 2 to 3 weeks' storage with bulbs attached or 1 week with bulbs removed is more practical (*672*). Storage at 2° is too warm for long-term storage. Stems of tulips will elongate if they are stored in water more than 2 days at 4°, and elongation is undesirable. Bunched tulip buds have also been held satisfactorily for 6 to 8 weeks at 0° in consumer packages overwrapped with moistureproof cellophane, polyethylene, or other films (*125, 667, 990*). Packages should not be airtight, as tulips may be injured by excessive accumulation of carbon dioxide (*990*). Tulips if stored dry in boxes should be kept vertical, with the blooms up, to prevent any undesirable bending.

Tulips should be harvested when the buds are half colored or when they have just acquired full color but are still fairly tight (*45*). Wrapping with newspaper before storage for protection is recommended.

Violets (sweet) are usually made up in bunches of 100, supported underneath by a collar of galax leaves. The bunches should be wrapped in light waxed paper and stored at 1° to 4°C. They will keep up to 1 week at this temperature but will slowly lose their odor after about 3 days. As a rule, they are not stored in water.

Florist Greens (Decorative Foliage)

The recommended storage temperatures for many of the florist greens available on the market are listed in table 15. These temperatures are based partly on information obtained from the trade and partly on laboratory research. Most species of florist greens are not highly perishable, given reasonable care, and can be handled or shipped over a period of several days with little or no damage. An environment of low temperature and high (90 to 95 percent) relative humidity is the best to retard deterioration and maintain foliage quality. Most florist greens are packed in moisture-retentive corrugated boxes, waxed boxes, wax-impregnated boxes, or polyethylene-lined boxes. Wet newspaper also may be packed around the foliage to retard moisture loss. Crushed ice may be added to lower the temperature, and the boxes are left open in a 2° to 3°C refrigerator to hasten cooling (*891*). Some florist greens

are collected and packed in the fall for extended storage; these are usually stored at about 0°. If only one controlled temperature room is available for a cultivar of greens, 4° is acceptable. When florist greens are removed from storage and placed in marketing channels, they usually need not be held at a temperature below 4°. They ordinarily move to the retailer within a few days and are used within a week.

When boxes arrive at the retail level, they should be opened and the greens sprinkled to avoid drying. Some types of greens such as holly, huckleberry, salal, and chamaedorea palms are left in the moisture-retentive boxes. Other types are removed, recut at the stem base, and placed in containers of warm (38°C) preservative solution in a 2° to 5° storage room for several hours before use. Some greens that benefit from holding in preservatives are boxwood, leatherleaf fern, camellia, eucalyptus, ivy, scotch broom, and podocarpus (*891*). However, most foliage greens last longer than flowers, so preservatives are less essential for greens. Recutting the stems of some foliage, such as emerald palm and ming fern, before placement in containers will extend longevity markedly. Illumination of 1,100 to 2,200 lux (100 to 200 fc) is desirable for 16 hours daily. Light prevents the onset of early chlorosis.

Tropical decorative foliage such as Hawaiian ti, podocarpus, and palms should not be exposed to temperatures below 7°C; otherwise, they may suffer chilling injury.

The storage life of florist greens depends on many factors, including maturity, handling temperature, and storage temperature. Because of this variability and because of lack of information, length of storage period generally is not given in table 15. American, Chinese, and English holly (*Ilex, opaca, I. cornuta,* and *I. aquifolium,* respectively) can be stored up to 5 weeks at 0°C or 2 weeks at 4°, if protected from excessive drying (*263, 1071*). Tight packaging should be avoided to prevent heating and subsequent discoloration of leaves. Waxing can improve gloss of holly leaves and berries but does not materially aid in reducing moisture loss. Dipping sprays of holly into a hormone such as alpha-naphthaleneacetic acid after harvest will aid in reducing leaf abscission for at least 10 to 14 days (*624*). Defoliation may result when holly is exposed to ethylene or held in nonperforated plastic bags, where ethylene produced by the berries accumulates. Hormone-dip treatments are also useful in controlling abscission of leaves and berries in film-packaged mistletoe (*850*). Mistletoe, if protected from dehydration, should keep at least 3 to 4 weeks at 0° and 2 weeks at 4°.

Leatherleaf (Baker) ferns are now successfully exported from Florida to Europe by ship in van containers with thermostats set at 3°C. Excellent arrival condition has resulted from proper precooling, moistureproof packaging, good loading patterns that allow air circulation, and proper refrigeration (*628*). Prompt precooling is essential to prevent decay. Recent research in Florida showed that fronds stored at 4.5° had less decay and greater longevity than fronds stored at 24° (*912*). Leatherleaf can be stored at least 1 month at 4.5° and still have a good vase life.

The presence of even minute quantities of ethylene gas in greenhouses, in storage, or during transport may greatly damage the keeping quality of some florist greens. Common symptoms of ethylene injury include epinasty (downward bending of leaves), dropping of leaves or berries, and yellowing of foliage. Leatherleaf fern is not affected by ethylene. (See also *63*.)

Bulbs, Corms, Rhizomes, Roots, and Tubers

The need for and length of storing bulbs depend on where the bulbs are grown and for what purpose. It is not possible to make hard and fast rules on bulb and corm storage. With many bulbs, cold storage immediately after digging and curing is not desired. Instead, they should be held at warm temperatures to allow the flower parts to develop within the bulbs. Later they may require storage at a lower temperature to prevent sprouting and at a relative humidity low enough to prevent rooting but high enough to retard moisture loss.

Fleshy bulbs, roots, and similar products (for example, lily bulbs, peony roots) may be injured by curing at too high temperatures and too low relative humidities. These commodities should be placed in cold storage in slightly damp packing material if they are to be held for later planting. Included in this category are items that do not have a rest period and also those that do not grow well until after a period of low temperature. A review of the cold requirements of bulbous plants for their flower induction and development has been published (*358*).

Many bulbs and corms are stored in trays, shallow boxes, or mesh bags in dry, well-ventilated rooms with no special packing. The following kinds are stored this way but are packed in wood shavings: Camassia, chionodoxa, calchicum, endymion, *Fritillaria imperialis,* oxalis, scilla, pushkinia, and *zantedeschia* (calla lily). Another group of bulbs, tubers, and roots are packed in cases with peat moss, sand, rice hulls, or vermiculite to prevent drying out (*191*):

Achimenes	Galtonia
Alstroemeria	Gloriosa
Begonia	Hemerocallis
Caladium	Hymenocallis
Canna	German iris
Dahlia	Lilium
Eranthis	Ranunculus
Galanthus	Tigridia

Most bulbs, especially spring-flowering ones, should not be exposed to ethylene, whether from ripening fruit or other sources, because of possible injury (*190*).

The recommended temperatures and approximate storage periods for specific bulbs, corms, rhizomes, roots, and tubers are given in table 15. The optimum temperatures should be used for these products whenever possible. Special temperature treatments are often given bulbs by bulb forcers to cure them, to break dormancy, to induce early blooming, or to time crops for certain holidays. Holding some species of bulbs for 4 to 6 weeks at 2° to 10°C after floral development is completed but prior to planting hastens flowering. This treatment, known as precooling, should be applied at a low (50 percent) to moderate (75 percent) relative humidity with good air circulation. The numerous programming schedules and precooling temperatures for forcing various bulbs to flower on different dates are too extensive and complex to list here, but they are available in the Holland Bulb Forcer's Guide (*190*). Another publication (*191*) lists the postshipping temperatures and storage conditions for Dutch-grown (wholesale) bulbs for dry sale and home use.

Caladium tubers should not be exposed to temperatures much below 21°C; otherwise sprouting will be inhibited. The tubers are extremely sensitive to low temperature and are easily cold injured. Even 10 days at 15° may inhibit sprouting. The dried tubers should be packed in dry peat or sand and stored in a dry, well-ventilated area at 21° (*578*).

Freesia corms when freshly harvested are stored at 30°C for 10 to 13 weeks to ensure rapid shoot emergence when replanted. Storage at 3° to 5° immediately after harvest maintains corm dormancy (*193, 479*).

Gladiolus corms after a curing treatment of 10 days at 27° to 29°C can be stored dry at a temperature range of 7° to 10° with relative humidity at 75 to 80 percent. They require several months at low temperature to overcome dormancy and should be stored in flats with spacing for air circulation. Prestorage fungicidal treatment of gladiolus corms for protection against infection by *Fusarium, Botrytis,* and *Stromatinia* is desirable. They should also be dusted for protection from thrips. Research on use of controlled atmospheres for corm storage showed that sprouting was suppressed and flower yields were reduced (*581*).

Hyacinth bulbs after digging are always cured—that is, held at 25° to 27°C—for several weeks to accelerate the development of flower parts within the bulbs. When such hyacinth bulbs are received in the fall for forcing, those intended for early forcing should be potted at once or stored at 9° to 13° until potted. This will act as a partial precooling treatment (*190*). Bulbs for regular forcing should be unpacked and spread out in shallow boxes, never in paper bags or corrugated cartons, and stored at 17° until needed for planting (*191, 666, 929*). Hyacinths can root prematurely under high humidities. Wholesalers handling Dutch hyacinth bulbs for home gardens should store them at 20° (*191*).

Dutch iris bulbs should be cured for 10 to 15 days at 32°C after harvest (*288*). Then they should be held at 18° to 24° for at least 2 to 3 weeks before being placed in cold storage for precooling. The recommended temperature for holding Dutch iris bulbs at the wholesale level for home use is 20° to 25° in a dry well-ventilated place (*191*). Bulbs to be stored for prolonged periods should be examined for aphids. Dutch iris to be forced should be precooled for 6 to 8 weeks at 10°, depending on the cultivar. For late forcing, bulbs should be stored at 25° to 29°, which prevents them from sprouting and keeps them dormant. Then they still must be precooled before planting. (For other details see *288, 298, 929, 931*.) **German iris** bulbs are stored at 0° to 5° in peat (*191*).

Easter lily bulbs are dormant when harvested, and most species can be stored at room temperature for a few weeks provided they are prevented from taking up moisture (which encourages rooting, sprouting, or rotting) and prevented from drying out (which devitalizes them) (*93*). In the production areas of California and Oregon, bulbs are packed in moist peat for shipment and held for a minimum time in common storage before they are shipped away. Some cold storage (precooling) of Easter lilies is necessary before forcing for potted plants. Lily plants grown from bulbs that have never been cooled and have always been exposed to temperatures of 21°C or above will never flower. Generally, 6 weeks of storage at 1.5° to 7°C in polyethylene-lined boxes with peat is adequate for accelerated blooming of freshly harvested mature bulbs (*929, 1038*). A temperature of 4.5° is satisfactory for venalization before forcing of both Ace and Nellie White cultivars.

A phenomenal amount of research on storing and forcing lilies has been done recently. Readers should consult reference *1038* for review.

For extended storage of several months, lily bulbs should be packed in air-dry peat in polyethylene-lined boxes and stored at −0.5°C. The plastic prevents loss of water, and the dry peat and low temperature discourage rooting, sprouting, and disease development (*928*). When bulbs are packed this way, they should go into storage at once. If either the moisture content of the peat or the storage temperature is too high, heat may build up and damage the bulbs. The moisture content of the material in which the bulbs are packed for storage can affect the time of blooming by a month or more. For earliest bloom, the peat should contain more moisture than it should when long storage is planned (*93, 767, 928*).

Lily-of-the-valley (convallaria) pips are kept frozen in storage at −4° to −1°C and are available for planting at any time of the year.

Narcissus bulbs cured at a high temperature of 30°C for 4 days can be stored dry at 17° until needed for late fall outdoor planting. This temperature is desirable for wholesalers or home storage (*191, 929*). A relative humidity of 70 to 90 percent is best to prevent rooting and mold

growth. Narcissus intended for early forcing should be precooled for about 6 weeks at 9° to 10° and then placed in flats containing well-drained soil for another 4 to 6 weeks' storage in a 9° to 10° bulb cellar. If not ready for planting or precooling, bulbs should be held at 13° for cut narcissus production or 17° for pot narcissus. Sometimes, narcissus bulbs intended for latest blooming are not precooled after harvesting and curing in July but are held at about 17° until planted in November. (See *190, 298, 666, 929.*)

Peony roots stored for spring sale should be packed in peat moss and held at 0° to 2°C to prevent sprouting and drying.

Tulip bulbs are usually cured 1 week at 26°C and then stored dry at about 17° with good ventilation and 70 to 90 percent relative humidity. A holding temperature of 17° is recommended for wholesalers selling bulbs for home use. Warm temperatures are necessary for flower bud initiation, but cool temperatures are needed to promote bud elongation. Temperatures above 26° for extended periods delay bud formation and may even kill the growing point (*930*). Many forcing regimes for different tulip cultivars have been developed to produce cut flowers or pot plants in different months (*190*). Bulbs usually are held at 17° until flower differentiation is complete and the stamens are clearly visible when bulbs are cut. One suggestion for early cut flower production is to precool the bulbs for 6 weeks at 4° and then store them for 4 to 6 weeks at 9° to 10° before forcing. The 4° temperature promotes earlier flowering and formation of longer stems than does continuous storage at 10° (*929*). For earliest outdoor flowering, tulip bulbs may be stored dry for 3 weeks at 20° and then for 8 weeks at 9° to 10° before planting. Some tulip cultivars require a much longer period at a given temperature than others. Forcing programs for Dutch tulips to flower during seven different periods are outlined in reference *190*.

The storage temperature for nonprecooled tulips prior to planting depends primarily on the intended use of the bulbs. If the bulbs are to be forced for cut tulips production, a temperature of 13°C should be utilized because it helps to produce taller plants. Bulbs forced for pot plant use should be stored at 17° because it helps to produce shorter plants (*190*).

For extended storage of 5 to 6 months, as required, for example, for bulbs to be shipped to the Southern Hemisphere, a temperature of −0.5° to 0°C is recommended. Research at Michigan State University showed no advantage of shipping tulip bulbs overseas under hypobaric conditions of 76 or 150 mm Hg at 17° over the present practice of shipping them in temperature-controlled containers (*192*). Bulbs from Holland are transported by ship in conventional refrigerated van containers with thermostats set at 19° for the 2-week trip to the United States (*468*).

Crocus, *Iris reticulata,* and **muscari** arriving from The Netherlands, should be inspected and ventilated. If it is time for forcing, they should be precooled at 9°C. Nonprecooled bulbs should be held at 17° (*190*). Open trays are advised if these bulbs are to be stored for any appreciable period.

For further details on curing, forcing, and storing bulb and root crops, which involve temperature manipulation, see the following: General, *44, 123, 181, 190, 191, 358, 471, 666*; dahlia roots, *27, 181*; gladiolus, *182*; gloriosa, *261*; and tuberous begonia *560*.

Flowering Potted Plants

Relatively little postharvest handling research has been done on flowering potted plants. Plants are normally sleeved and boxed for ease of handling and protection during shipment. The sleeves of paper or plastic provide some protection from cold weather but mainly in handling (*909*). Four days is believed to be the maximum period for keeping most flowering plants boxed (*723*). The faster plants can be removed from the boxes, the greater the retention of quality. Mass marketers should rely on fast turnover so that the plants are not in stores any longer than necessary. Most flowering plants should be kept at a temperature range of 13° to 18°C during brief storage or in transit and of 13° to 24° during retail marketing (*723*). Temperatures below 7° permanently damage most flowering plants, except bulbous plants and lilies. The life of bulbous plants can be extended if they are stored at 4°. Temperatures above 27° to 29° will damage plants, especially closely packed plants (*891*).

Some plants that will keep decorative longest at a temperature of 13°C are calceolaria, cineraria, cyclamen, and chrysanthemum. If chrysanthemum plants require actual storage for more than 5 days, 3° is a good temperature. Sleeved poinsettias will tolerate 10° for up to 4 days even though they are tropical plants. Lower temperatures such as 2° to 7° will be disasterous, causing excessive leaf-drop when poinsettias are returned to a warm temperature (*910*). Easter lilies can be successfully stored in the dark at 0° to 3° for 2 to 4 weeks if the flower buds are in the white puffy stage (not open) (*1038*). A temperature of 1° to 3° is desirable for holding or shipping potted roses for 5 or 6 days to prevent bud and leaf abscission (*311*). This was determined in simulated shipping tests with sleeved and boxed roses. Severe abscission of buds and leaves occurred in some rose cultivars shipped at a warm 20°. African violets do not store well and do not tolerate temperatures below 13°. They will drop their flowers if left in complete darkness for several days or if exposed to air containing ethylene gas.

Close attention to watering plants is essential during storage and marketing. Flowering plants should neither be permitted to dry so much that they wilt nor be allowed to stand in water (*723*). Daytime light intensities of 1,600 to 4,300 lux are optimum after plants are removed from shipping boxes for sale. However, few sales areas provide even the minimum 1,600 lux (150 fc).

Foliage Plants

The many popular kinds of foliage plants are not stored in the usual sense of a harvested crop, since they have an unlimited life under good growing conditions. However, they do have to be shipped long distances to market, so temperature control is desirable to retain quality in the darkness of transport vehicles. The shipping environment is not conducive to maintaining foliage plant quality (*166*). Although it is difficult to generalize, the best shipping temperature is in the range of 15° to 18°C, with 85 to 90 percent relative humidity (*167, 909*). Temperatures of 10° to 13° are the lowest that should be considered for shipping, and even at this range some chilling injury may occur with some plants. All foliage plants should be acclimatized by suppliers prior to shipment. (Acclimatization is the process of making plants more tolerant to changes in environment during or after shipment.) Table 17 suggests shipping temperatures for some acclimatized plants in refrigerated vans. These data are based on simulated shipping tests in darkness. Growers acclimatize plants by using lower fertilizer levels, lower temperatures, and/or reduced light and water during the last 2 to 4 weeks before shipment. Acclimatized plants are better adapted to dark storage in transit and reduced light in stores than nonacclimatized plants.

In simulated shipping tests at 10°, 13°, 16°, and 19°C for 1 to 4 weeks in the dark, ***Schefflera arboricola*** shipped best at 10°, ***Ficus benjamina*** at 10° or 13°, and ***Dracaena marginata*** equally well at 13°, 16°, and 19° (*724*). These plants withstood shipment for 3 weeks without significant loss of quality and for 4 weeks at some temperatures without severe quality reduction. Shefflera plants recovered from dark storage within 17 days after transfer to light (*77*). ***Ficus*** foliage plants are damaged by holding at 4° for 6 or more days. Similar chilling injury can occur on many foliage plants if the air temperature drops to 7° for long periods or to 2° to 5° for even relatively short periods.

Table 17
Suggested shipping temperatures for acclimatized foliage plants to maintain quality in refrigerated vans[1]

Plant name	1-15 days' shipment		16-30 days' shipment[2]	
	°C	°F	°C	°F
Aglaonema, cv. Fransher	13-16	55-60	16-18	60-65
Aglaonema, cv. Silver Queen	16-18	60-65	16-18	60-65
Ardisia crispa	10-13	50-55	—	—
Aspidistra elatior	10-13	50-55	—	—
Brassaia actinophylla	10-13	50-55	10-13	50-55
Chamaedorea elegans	13-16	55-60	—	—
Chamaedorea seifrizii	13-16	55-60	—	—
Chrysalidocarpus lutescens	13-18	55-65	16-18	60-65
Codiaeum variegatum	16-18	60-65	16-18	60-65
Cordyline terminalis	16-18	60-65	—	—
Dieffenbachia picta	16-18	60-65	—	—
Dracaena deremensis	16-18	60-65	—	—
Dracaena fragrans	16-18	60-65	—	—
Dracaena marginata	13-18	55-65	16-18	60-65
Ficus benjamina	13-16	55-60	13-16	55-60
Ficus nitida	13-16	55-60	—	—
Howeia forsteriana	10-18	50-65	10-18	50-65
Nephrolepis exaltata	16-18	60-65	—	—
Peperomia bicolor	16-18	60-65	—	—
Philodendron selloum	13-16	55-60	—	—
Philodendron oxycardium	16-18	60-65	—	—
Phoenix roebelenii	10-13	50-55	—	—
Pleomele reflexa	16-18	60-65	—	—
Rhapis excelsa	10-13	50-55	—	—
Schefflera arboricola	10-13	50-55	10-13	50-55
Scindapsus aureus	16-18	60-65	—	—
Spathiphyllum, Mauna Loa	10-13	50-55	13-16	55-60
Yucca elephantipes	10-13	50-55	10-13	50-55

1 Adapted from references *167, 909*. Data are for plants in containers in the dark. Some plants stored without lights for 10 to 14 days will show slight to severe leaf loss and/or yellowing but will recover.
2 Blanks indicate that plant's tolerance to shipping beyond 15 days is unknown.

Although 1 day's exposure at 5° may not damage most foliage plants, fairly severe damage can occur when plants are subjected to cool temperatures over a 3- to 5-day transit time. Coleus is very cold sensitive. ***Dracaena sanderana*** and ***Spathiphyllum clevelandii*** are severely injured after 1 day at 2° and slightly chilled after 1 day at 10° (*580*). ***Aglaonema*** is very intolerant of storage temperatures below 10°. Exposure to 4.4° for 2 days causes severe damage to ***Scindapsus pictus*** (satin pothos) and ***Maranta leuconeura*** (prayer plant). ***Fittonia verschaffeltii*** (silvernerve plant) is very chilling sensitive and is severely damaged within 8 hours at 2° (*612*).

Foliage plants should be turned over rapidly in marketing and should not be overordered. Plants should not be stored in back rooms for extended periods or in severe drafts of heat or cold. Foliage plants should not be transported with fruits, vegetables, or cut flowers—all of which emit ethylene and are shipped at low temperatures. Plants such as scheffleras, crassulas, fittonias, and ficuses are very sensitive to ethylene at a level as high as 5 p/m (*420*).

Cuttings and Scions

Cuttings are sometimes stored for future use. Refrigerated storage is useful in extending the life of cuttings by retarding respiration, transpiration, defoliation, and growth of pathogens (*357*). Low temperatures (0° to 4°C) and the use of fungicides prolong the storage of several kinds of rooted cuttings for up to 6 months (*250*). Storage periods are generally shorter for unrooted cuttings than for rooted cuttings. In general, the more succulent the material, the shorter the storage period. Unrooted softwood **azalea** cuttings in polyethylene bags can be stored 4 to 10 weeks at −0.5° to 4°C (*742*). Kurume-type softwood azalea cuttings root more quickly after 4 weeks' storage than those with no storage.

Carnation cuttings, either rooted or unrooted, store well and can be kept 5 to 6 months at −0.5° to 0°C in polyethylene-lined boxes or film bags. The film should not be sealed airtight. Sometimes a small quantity of peat or sphagnum moss is packed around the roots or base of the cuttings within the bags (*400, 592*).

Some cultivars of unrooted, unhardened **chrysanthemum** cuttings can be stored 5 to 6 weeks at −0.5° to 0.5°C if protected with moistureproof packaging such as polyethylene bags. Cuttings stored longer than this usually recover more slowly and make less growth. Fall-dug stool cuttings (unrooted) packed in polyethylene bags with most of the leaves removed can be stored successfully up to 6 months at −2° to 1° (*544*). Rooted chrysanthemum cuttings can be stored satisfactorily 3 to 6 weeks at −0.5° to 1.6°; storage time depends on the cultivar (*493*). Storage life is reduced at the higher temperature. Low pressure storage of chrysanthemum cuttings is used successfully by Yoder Brothers, Fort Myers, FL.

Rooted **poinsettia** cuttings may be stored 1 week at 5°C and up to 3 weeks at 5° in hypobaric storage (35 mm Hg). Unrooted poinsettia cuttings are much more difficult to store (*230*).

Unrooted **geranium** cuttings from disease-free plants can be stored at −0.5°C for 4 to 6 weeks. They must be stored dry in moistureproof containers. At 5°, the storage life is only 2 weeks. Hypobaric storage has been reported as aiding longevity of geranium cuttings (*230*).

Regel's **privet,** tallhedge **buckthorn,** and cranberry bush **viburnum** as unrooted cuttings have been stored 6 weeks at 1° to 2°C with 95 percent relative humidity (*230*). Rooted cuttings of numerous kinds of **woody ornamentals** including **evergreens** can be stored 5 to 6 months at 0° to 2°. Sphagnum or other moss is not needed if the bare-rooted cuttings are stored in polyethylene bags. Successful storage tests have been conducted with ***Taxus, Teucrium, Thuja, Euonymous, Ilex,*** and ***Juniperus*** (*250, 816*). Sometimes it is desirable to harden cuttings before storage. Hardening of rooted cuttings is accomplished by lowering greenhouse temperatures, by reducing the water supply, and by placing the cuttings in a 4° chamber for 4 days prior to low-temperature storage.

Tropical foliage plant cuttings are usually wrapped in paper with sphagnum or peat moss around the basal ends or roots and packed into waxed cartons. Shippers of tropical cuttings normally try to maintain temperatures of 15.5° to 18.5°C (*165*).

Dormant **raspberry** propagation canes cut to approximately 15 cm, tied in bundles, and packed in perforated polyethylene bags keep well in cold storage for 12 to 15 weeks at −1.0°C. This temperature (−1.0°) is better than 1.7°, since shoot growth is retarded during storage. Any shoot growth necessitates very careful handling (*69*). Large-diameter canes produce larger plants than thin canes.

Blueberry propagation canes (unrooted 10-cm cuttings) should be stored at −1°C in nonsealed polyethylene-lined containers. Storage for at least 5 months is possible (*1063*). Cuttings stored at 10° develop top growth and do not root as well as cuttings stored at −1° or 4°. The poly bags may, but need not, contain peat. Freezer storage at −18° or below should be avoided, as the wood is injured and survival is very poor. Hardwood cuttings from canes of highbush blueberries collected in early dormancy and stored at 2° in poly bags until spring root better than cuttings collected in the latter part of winter (*831*).

Rose budwood canes can be kept in good condition for as long as 24 months at −2° to −0.5°C. This temperature is not cold enough to freeze the tissue of mature budwood canes. Canes are cut into lengths up to 40 cm, bundled, and wrapped in polyethylene. Soaking-wet newspaper is then wrapped around each polyethylene-wrapped bundle, and this is again wrapped with polyethylene or moistureproof paper. Bundles are then packed in cartons for storage.

Ethylene is injurious to many kinds of cuttings and scions. Dormant **apple scions** placed in plastic bags and stored with ripening apples for 1 month at 1° to 2°C were injured. The scions developed lenticel hypertrophy and severe swelling and bark splitting at the apical ends (*438*). (See also *403*.)

Bedding Plants and Seedlings

Flower and vegetable **bedding plants** can be kept in salable condition for a month or more if their environment is closely controlled. Long holding is often important to extend the availability of bedding plants or to avoid planting them in adverse weather. In tests at Michigan State University (*663*), alyssum, pepper, petunia, salvia, begonia, coleus, geranium, impatiens, marigold, and tomato bedding plants at the right marketing stage were stored at 4°, 13°, 21°, and 29°C for 36 days under three light intensities. Marigold, impatiens, salvia, pepper, and tomato plants kept best at 13°. The impatiens plants were still marketable after 36 days at this temperature. Alyssum and geranium bedding plants stored equally well at 13° and at a chillier 4°. Petunia and begonia kept about equally well at 13° and 21°. Only coleus thrived best at 29°, the warmest holding temperature tested. The impatiens plants showed evidence of chilling injury (wilting

and desiccation) after 3 days at 4° and were not marketable. Bedding plants fared better when held in high light at 7,500 lux than at 500 or 2,700 lux.

Researchers in Georgia (*52*) found that after greenhouse production, petunia bedding plants kept better at a constant cool temperature of 10°C than at a moderate temperature of 20°. The shelf life of petunias was about 15 days stored at 10°, and light intensity was of little importance to their quality (*53*). Petunias should be held at either medium or low light intensity if held at 20° or higher after production. Bedding plants should be shaded from the sun during marketing.

Production conditions in the greenhouse have an effect on the postproduction life of bedding plants. Both marigolds and impatiens have a longer shelf life when grown the last 2 or 3 weeks with night temperatures of 10°C and 16°, respectively, than when grown with higher night temperatures (*664*). Marigolds grown the last 2 or 3 weeks with 10° night temperature and then stored at 10° after production had a 17-day marketable period. Impatiens had a shelf life of about 15 days at either 10° or 21° if grown the last 2 to 3 weeks with 16° night temperature. Research has shown that container depth (soil volume) has an effect on bedding plant shelf life (*267*). Plant life before wilting was significantly longer with containers 10.2 cm deep than with containers 5.1 cm deep.

Ethylene is known to be harmful to bedding plants. Impatiens held in 10 p/m ethylene lost all their flowers within 6 hours. Salvia held in 10 p/m ethylene was almost completely defoliated after 48 hours' exposure. Fumes containing ethylene from heaters or exhaust gases from forklift trucks or transport vehicles must be kept away from plants (*663*).

Sometimes it is desirable to maintain **flower seedlings** at the proper stage for transplanting. Research at Cornell University (*484*) showed that after reaching the "right size," some kinds of seedlings can be successfully kept at that stage for 2 weeks or more by storage at 1.1° to 4.4°C. The flats of seedlings are thoroughly watered and then placed in polyethylene bags. In storage, seedlings should receive light 14 hours a day; fluorescent lights should be about 30 cm (12 in) from the seedlings. Flower seedlings that can be stored at least 2 weeks at 1.1° to 4.4° under lights include alyssum, aster, browallia, dianthus, geranium, lobelia, marigold, petunia, salvia, snapdragon, and stock. Snapdragon, alyssum, petunia, and salvia can be stored for as long as 6 weeks. Seedlings that can be successfully stored for 1 to 2 weeks are ageratum, cineraria, cosmos, pepper, and tomato. Storage of zinnia and coleus seedlings by this procedure was not successful. After storage of 1 to 2 weeks, seedlings can be planted immediately. If seedlings are stored longer than 2 weeks, they should be removed from cold storage and placed in a shaded cool location for 24 hours before they are planted.

Growers should use extreme care in handling and storing seedlings to prevent contamination and loss from damping-off diseases under moist conditions.

Conifer seedlings and many **hardwood forest seedlings** can be stored 3 to 6 months at 0° to 2°C and 90 to 95 percent relative humidity without impairing survival (*22, 47, 216*). Often the humidity is kept high by using moistureproof packaging. For example, bundles of bare-rooted seedlings are placed in polyethylene bags, adequate spacing between the bags being provided in storage for good air circulation. Sometimes loosely tied bundles of 50 seedlings are packed with moist peat around the roots and wrapped in film-coated kraft paper with the tops exposed. These bundles are then stored in metal or fiberboard containers. Moisture losses can be held to 1 to 2 percent during several months' storage. Seedlings should be dry when stored to avoid mold development. Seedlings of the following species are successfully stored for 3 to 6 months: Norway and Sitka spruces, Douglas fir, Western hemlock, Lodgepole and Scotch pines, Lawson cypress, *Abies grandis,* oak, and birch. Japanese larch was not suited to long-term cold storage (*22*). Refrigerated vans now are used to transport and store millions of conifer tree seedlings. They can be stored in the vans at planting sites until planting conditions are satisfactory (*47*).

Seeds and Pollen

It is not generally realized how quickly seeds may deteriorate under conditions of high temperature and high humidity. Vegetable seeds will have a large loss of viability within 3 to 6 months if stored at 21°C and 90 percent relative humidity (*436*). Seeds must be stored at a comparatively low temperature and low relative humidity to maintain viability and high vigor. However, for storage from harvest to planting time, most seeds require no special storage conditions in temperate or cold climates. For such storage in warm humid regions, low temperature and dehumidification are usually required. The general rule is that the longer the storage period, the lower the relative humidity and temperature required. A temperature of 0° is desirable for seed storage, but 10° is satisfactory for practical purposes provided that the relative humidity is kept near 50 percent. Under the latter conditions most seeds will keep a year and some kinds much longer (*70, 955*). Seeds should be stored dry and kept dry.

For extended periods of storage, seed moisture content and storage temperature are the most important factors to control, with seed moisture being the more critical (*357*). Seed moisture content can be controlled either by drying seeds to the desired moisture content and then storing them in sealed moistureproof containers or by storing the seeds in porous containers under controlled low-relative-humidity conditions. For most common seeds, the optimum seed moisture content for sealed storage is between 3 and 7 percent (*73, 350*). For controlled storage, a relative humidity of 50 percent or lower is recommended. In one study (*444*), various kinds of seeds stored at 10°C and 50 percent relative humidity showed no loss in viability

during 5 years of storage. Comparable results can be obtained by drying seeds to 5 percent or lower moisture content and storing them in sealed moisture-barrier containers at ambient temperatures. Some kinds of flower seeds retain 50 percent of their original viability after 5 to 10 years in dry storage without temperature control. However, cold storage at 0° to 10° with low relative humidity is preferred when full viability is to be maintained for 1 year or longer.

Freezing temperatures are sometimes used for extended storage of seeds that are air-dry or drier. Temperatures of −18° to −20°C are actually better than zero or higher for many kinds of seeds. Some exceptions are parsley, pansy, fern asparagus, snapdragon, and hybrid petunia seeds (*444*). To maintain quality for a long time (years) in storage, most kinds of seed should generally be dried to 3 to 7 percent moisture content, then sealed in a moistureproof container and stored at a temperature of −10° or colder, preferably colder (*72, 73*). Lettuce seed dried to less than 7 percent moisture, then sealed in moistureproof containers that excluded oxygen still germinated after 3 years at room temperature, after 8 years at −1°, and after 20 years at −12°. Many kinds of air-dried seeds can be stored in liquid nitrogen (−196°) for at least a year or two with little or no loss of viability (*73, 914*). The superiority of subfreezing temperatures than of higher temperatures for seed storage has been well established for many kinds of seeds, but not all. Liquid nitrogen offers promise for allowing the long-term storage of seed germplasm (*914*).

The various factors that affect storage life of seeds are genetic effects, preharvest effects, seed structure, seed maturity, seed size, seed dormancy, moisture content, vigor, processing methods, mechanical damage, and the storage environment. Storage fungi, insects, and rodents can increase losses. Insect infestation and damage to seeds are retarded at temperatures below 10°C, and most insect activity ceases at 0°. However, some insects and their eggs are not killed until freezing temperatures such as −18° are used.

Theoretically, storage of seeds in controlled atmospheres with reduced oxygen in sealed containers should increase their storage life. Results of studies in which various gases or partial vacuum were substituted for air in sealed containers indicate that for short-term storage, the time and expense of substituting low-oxygen atmospheres were not worthwhile. For long-term storage, such substitutions may or may not be worthwhile (*72, 73*).

Cold storage of **tree and shrub seeds,** used in nursery stock production, is advisable if seeds are to be held for 1 year or longer (*357*).

A study on the storage of **coniferous seeds** showed that they lost most of their viability in 4 to 5 years when stored in metal cans at 5°C (*822*).

Germinating seeds and seedlings of tropical or subtropical origin may be damaged by exposure to low, nonfreezing temperatures. Some kinds of seeds that are chilling sensitive during imbibition and germination at 0° to 15°C are pepper, muskmelon, snap bean, lima bean, sweet corn, and tomato (*1050*).

Pollen maintained excellent viability when stored 2 years at −20°C (*152*). Pollen stored at 20° with 14 percent relative humidity for 20 weeks showed only 30 percent germination. For long-term storage of pollen, which is important in plant breeding, it is best to air-dry the pollen to 10 to 30 percent moisture content prior to freezing.

Herbaceous Perennials

Many kinds of nursery stock can be stored successfully at temperatures ranging from −0.6° to 1.7°C (31° to 35°F). Some kinds are stored partially frozen for long periods at −2.8° to −2.2° (27° to 28°F). For storage at −2.8° to −2.2°, many operators use a small amount of excelsior on both the top and bottom of crates to minimize temperature fluctuations during freezing and thawing. After the crates are filled, they should be moved promptly into freezer storage if adaptable. Even though plant materials stored at −2.8° to −2.2° are usually not frozen solid, at least 12 to 14 hours should be allowed for thawing before handling and packing for shipment. They should not be handled in a frozen condition (*566*). For stock stored at −0.6° to 1.7°, great care in stacking is essential to ensure spacing that allows airflow necessary for prompt cooling.

Moisture loss during storage of perennials often can be minimized through the use of crates with polyethylene-coated kraft paper or polyethylene film liner.

Some plants are stored in small consumer packages ready for marketing, but bulk storage is more common, with grading and packing conducted after storage.

For many details on storage of nursery stock, including herbaceous perennials, and on storage construction and packaging methods, readers are referred to the excellent bulletin by Mahlstede and Fletcher (*566*). Storage-temperature information from this bulletin, for herbaceous perennials, is given in the following tabulation.

Storage temperature for various types of plant material[1]

−2.8° to −2.2°C (27° to 28°F):

Achillea (yarrow)
Ajuga (bugle)
Alyssum (goldentuft)
Anchusa myosotidiflora (Siberian bugloss)[2]
Aquilegia (columbine)
Arabis (rockcress)
Armeria (sea-pink)
Artemisia (silver-mound)
Aster (Michaelmas-daisy)
Campanula (purple bellflower)
Campanula calycanthema (Canterbury-bells)
Centaurea Cyanus (bachelors-button)
Cimicifuga (snakeroot)[2]
Convallaria (lily-of-the-valley)[3]
Coreopsis (tickseed)

[1]Data from (*566*).
[2]Fleshy roots are stored.
[3]Also stored satisfactorily at 0.6° to 1.7°C.
[4]Rhizome.
[5]Root mat.

Delphinium (larkspur)
Dianthus barbatus (sweet-william)
Dicentra formosa (bleedingheart)
Doronicum (leopardbane)
Echinops (globethistle)
Erigeron (fleabane)
Ferns[3]
Gaillardia (blanketflower)
Geranium (cranesbill)
Geum (avens)
Gypsophila (babysbreath)[2]
Helenium (sneezeweed)
Heliopsis (orange sunflower)
Heuchera (coralbells)
Iberis (candytuft)
Lavandula (lavender)
Liatris (blazing-star)
Limonium (statice)
Linum (flax)
Lobelia (cardinalflower)
Lychnis (campion)
Lythrum salicaria (purple loosetrife)[3]
Oenothera (eveningprimrose)[3]
Paeonia (peony)[3]
Papaver (poppy)
Penstemon barbatus (beardtongue)
Perovskia (Russian sage)
Phlox divaricata (blue phlox)
Phlox subulata (moss phlox)
Physostegia (false-dragonhead)
Platycodon (balloonflower)
Plumbago (burnst)
Pulmonaria (lungwort)
Pyrethrum (painted-daisy)
Rudbeckia (coneflower)
Salvia pitcheri (meadow-sage)
Sedum acre (goldmoss)
Sedum spectabile (showy stonecrop)
Spiraea (goatsbeard)[3]
Thalictrum (meadowrue)
Thermopsis
Tradescantia (spiderwort)[2]
Trollius (globeflower)
Veronica (speedwell)
Viola (violet)

0.6° to 1.7°C (33° to 35°F):

Aconitum (monkshood)[4]
Aethionema (dwarfcress)
Agapanthus (lily of the Nile)
Anchusa italica (alkanet)[2]
Dicentra spectabilis (bleedingheart)
Helleborus niger (Christmas-rose)
Polygonum (dwarf laceplant)
Stokesia (cornflower-aster)

0.6° to 4.4°C (33° to 40°F):

Althaea rosea (hollyhock)
Cypripedium (ladyslipper)[5]
Gerbera (transvaal-daisy)
Helianthus (sunflower)
Hibiscus (rosemallow)[2]
Iris (bearded iris)
Lupinus (lupine)

Woody Ornamentals

Many nurseries hold trees, including fruit trees, in common storage, where conditions are only partially controlled; some have mechanically refrigerated storage facilities providing desirable temperatures of 0° to 2°C. High humidity, near 95 to 98 percent, is desirable to prevent drying and can often be provided by covering the roots with shingle tow or sphagnum moss that is kept moist. In cold-storage rooms a humidifer can also be used, but good air movement over the stock is necessary. The chances for moisture loss are much greater for evergreens than for deciduous trees and bushes, because the evergreens are never without foliage. Plastic coatings or other transpiration suppressants are of some value in preventing excessive drying.

Successful storage of **deciduous plants** is dependent on their physiological maturity. Plants harvested prematurely are susceptible to freezing injury, metabolic breakdown, and possibly microbial infestation. At nurseries deciduous plants are considered to be mature if they can be successfully defoliated, harvested, and stored for long periods at relatively cool temperatures (*255*). Deciduous stock usually remain dormant in common storage during late fall and early winter, at first because of the normal rest period and later because of temperatures sufficiently low to prevent bud growth. Dormancy can be maintained in late winter and early spring if the temperature is kept near 0°C. Dormant shrubs that have been graded can be stacked on racks from floor to ceiling in storage. Nursery stock such as privet should be stacked close together with wet material on about every fifth layer of plants. Lining-out stock should be stored the same way at 0° to 2° with wet sawdust or moist moss used for packing material. Moisture-retentive film bags or crate liners are also beneficial (*566, 973*).

Winter storage of nursery plants in the colder parts of the country must provide protection from winter damage. Successful storage depends on providing sufficient protection so that plant injury does not occur. Common types of winter injury are foliage desiccation and root kill from low temperatures (*255, 379, 380*). To minimize the risk of winter injury to balled and burlapped and containerized ornamentals, nurseries overwinter plants in quonset-shaped polyethylene structures (fig. 10), underground storage structures, or aboveground barns provided with a vapor barrier. Any of these types of storage facilities can be used successfully if each is managed properly with regard to the requirements of the stored plants. They should pro-

Figure 10
Quonset-shaped polyethylene structures for storage of woody ornamentals. (Courtesy of University of Massachusetts.)

vide protection against too low night temperatures, which may damage roots, and high day temperatures, which may cause desiccation injury. Polyethylene-covered structures (4-mil) are satisfactory for plants with hardy roots, but some kind of special management is suggested for plants with relatively tender roots (*255, 379*). In general, double-layer, inflated film structures provide greater winter protection than single-layer films in the Northern States. They provide desired cooler maximum temperatures during winter storage. In tests with single-layer, white-pigmented films, shoot quality after storage was highest in structures covered with films of the highest opacities tested, 70 to 80 percent. The more standard, white poly-covered structure (50 to 60 percent opacity) does not provide adequate winter protection for all woody ornamentals in Ohio (*1074*).

Root hardiness is of prime importance in the storage of woody nursery stock. Lethal root temperatures ranged from −5° to −23.3°C for 38 different container-grown woody ornamentals in Massachusetts (*379, 380*). The roots of ornamentals growing in containers are more susceptible to injury from cold than those of similar plants growing in the nursery row (*287*). Plants that suffer extensive root damage from cold generally die in the spring when exposed to higher temperatures and longer days. By knowing approximate lethal root temperatures for different species, nurseries can segregate plants and provide needed amounts of protection in storage structures.

In areas where winters are less severe, many kinds of container-grown ornamentals may be protected by covering with various types of insulated thermoblankets (plastic-straw-plastic, microfoam, poly-air, polyfoam). These blankets should be sealed to the ground at the edges with gravel or soil (*287*). Polyethylene sheeting or thermoblankets (fig. 11) may also be used within storage structures to provide additional winter protection (*849*). Containerized plants should be placed close together before covering.

Figure 11
Nursery stocks covered to prevent foliage desiccation and to provide winter protection when stored in quonset-shaped polyethylene structure. (Courtesy of University of Massachusetts.)

Traces of ethylene, even 1 p/m, in the storage air can damage dormant nursery stock of apple, pear, and other fruit trees. Pear trees are particularly susceptible to damage (*184*).

Most of what has been said for woody ornamentals also applies to **evergreens.** The major differences in physiology and condition between evergreen and deciduous materials in the fall and early winter must be realized. Evergreens, as the name implies, are in full leaf, whereas dormant deciduous plants are without leaves. It is essential, therefore, that evergreens never be allowed to dry out, and watering may be necessary during storage.

Container-grown evergreens and balled evergreens wrapped in burlap or polyethylene are held in polyethylene-covered structures or in common or refrigerated storage (0° to 2°C). A temperature near 0° is optimum for several months' storage. These conditions help to retain good foliage color, prevent wind or other winter injury, and eliminate the need for spring digging, when weather conditions may be unfavorable. A Michigan study (*186*) showed that evergreens can be overwintered successfully without irrigation if the polyethylene structure is oriented in a north-south direction and covered with white polyethylene rather than clear. Sometimes nurseries use underground cellars with dirt floors covered with shingle tow. The balled stock should be separated enough so the foliage is not crowded, and damp moss or shingle tow should be packed on all sides of the balled stock (*566*). (See also *248, 848.*)

High levels of carbon dioxide (40 percent) can aid in inhibiting root and shoot growth of nursery stock (*956*), but apparently there has been no commercial application.

Rose bushes are often stored 4 to 5 months, from fall until spring planting, at −0.5° to 2°C with 85 to 95 percent relative humidity. Before storage, the plants are defoliated and pruned to about 25 to 30 cm (10 to 12 in), as needed, and the canes dipped in a fungicide to hold down mold. Most rose bushes are now stored bare rooted with no moss or excelsior and are sprayed frequently

with water to keep them moist, especially the roots. The fungicide treatment and frequent spraying help protect against the chief problems that arise during storage—decay and desiccation. Another satisfactory packing method for bare-rooted bushes is to place them in containers lined with polyethylene-coated kraft paper, which is effective in restricting moisture loss (*565, 566, 973*). Bushes are stored in pallet boxes or bins holding 400 to 500 plants. Any stacking arrangement of containers should allow good air circulation. Rose bushes are injured by ethylene; hence, they should not be stored with apples or other products producing large amounts of ethylene. Usually at the time of consumer packaging, before marketing, wax (melted paraffin) also is applied on the canes of the dormant rose bushes to retard moisture loss and reduce respiration (*957*). The respiration rate of dormant bareroot rose bushes at 0° expressed as carbon dioxide production is 10 to 15 mg/kg•h. (See also *1078*.)

Miscellaneous Plants and Christmas Trees

Asparagus Plants (Rhizomes)

Asparagus rhizomes should be stored at −1° to 0°C with a room relative humidity of 85 to 90 percent. The rhizomes, which are not generally stored for more than 3 to 4 months, can be stored in closely woven burlap bags or in perforated polyethylene bags. The roots of the plants need not be as long as 40 to 60 cm (16 to 24 in) but may be trimmed to 20 cm (8 in) length from the crown. Trimming saves storage space and reduces shipping costs and should not impair the field survival of the plants (*1065*).

Strawberry Plants

Strawberry plants for storage can be dug in the fall or early winter when fully dormant and stored at −1° to 0°C (preferably −1°) in crates with a lining of 1.5-mil polyethylene and a capacity of 500 to 2,500 plants. The film should be folded over the plants but not sealed. Bare-rooted plants can be stored under these conditions for 8 to 10 months (*1062*), and no sphagnum moss is needed. Research has shown that most strawberry plants can also be dug in the fall when nondormant and be stored successfully for 5 months at −1°. This practice avoids winter injury without causing loss of salable plants (*1064*). Storage temperatures below −1° will injure strawberry crowns and result in poor field performance. Temperatures much above −1° may be detrimental because they may allow top and root growth. Excessive soil and debris should be removed from plants before storage in film. Leaves may be removed from nondormant plants prior to storage without adversely affecting subsequent field response. If free moisture is seen in the polyethylene liners, the temperature is not low enough. Such free moisture can encourage decay (*120*). For best results, plants should be cooled to −1° within 3 days of packing (*1066*).

The respiration rate of strawberry plants at 0°C expressed as carbon dioxide production is about 12 mg/kg•h.

Strawberry meristem plantlets in test tubes have been stored for up to 6 years in darkness at 4°C (*651*).

Tomato Plants

Tomato plants are not stored commercially other than for brief holding when conditions are unsatisfactory for planting. Desirable storage or transit temperatures are 10° to 13°C, and the combined transport and storage period should not exceed 10 days. Temperatures in this range are beneficial because they suppress new root growth. Plants stored at 4° grow more slowly after planting than those held at the recommended temperature. Tomato transplants are packed or handled in at least 4 ways: (1) bundles of 50 plants packed with moist peat around the roots and wrapped in kraft paper, (2) bundled or loose, bare-rooted plants placed in perforated polyethylene bags or crate liners, (3) bundled or loose bare-rooted plants placed in crates without a film liner, and (4) containerized plants in Styrofoam flats in which they grew (*626, 637, 765, 766*). For the plants in Styrofoam flats, a shipping-storage temperature of 4.4° should be satisfactory for 5 days or less (*766*).

Christmas Trees

Christmas trees cut several weeks before use benefit from refrigerated storage. Scotch pine, red pine, white spruce, and balsam fir cut November 1 and tied in bundles of four can be stored successfully at −5°C with 85 percent relative humidity until a week before Christmas and still have an adequate indoor life at 24° to 27°. Storage is slightly better at −5° than at 0° because of drying at 0°. Overwrapping trees with polyethylene is effective in preventing drying. Trees cut in September did not store well, since they had not developed their seasonal hardiness to cold at the time of cutting (*617*).

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